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Hypnotic susceptibility and postural control: role of attention and imagery

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Summary

Hypnotizability is a cognitive multidimensional trait involving, in particular, attentional and imagery abilities. Earlier findings have shown hypnotizability related differences in sensorimotor integration at reflex and postural level also in not hypnotized subjects. As postural control requires a complex sensorimotor integration and is modulated by attention, one of the aims (Part 2) of this thesis was to investigate the postural effects of sensory alteration (Study 1 and 2) and cognitive load (Study 3) in subjects with high (Highs) and low (Lows) hypnotizability scores. The results showed that Highs and Lows exhibit a different set point for postural control, that visual neck/leg proprioceptive and vestibular inputs have a different relevance in the required sensori-motor integration and that the different responses of Highs and Lows to sensory alteration do not depend on attentional availability. As imagery has shown a quasi perceptive role in Highs, the other aim of this thesis (Part 3) was to investigate whether the imagery of anaesthesia reduces the amplitude of vestibular reflexes and whether the imagery of head rotation changes their preferential sway plane differentially in Highs and Lows receiving transmastoid vestibular galvanic stimulation (Study 4). In fact, the vestibular reflex is known to be scarcely dependent on voluntary control and the direction of its main component varies with the position of the head with respect to the trunk. The results showed that high imagery ability accounts for the reduction of the vestibular reflex amplitude in both Highs and Lows during suggestions for anaesthesia, while high hypnotizability is required to change the preferential plane of sway during imagery of head rotation. This might be mediated by the Highs' greater proneneness to choose the somesthetic modality of imagery. In Study 5, it was shown that Highs, administered pain suggestion, can experience pain, also in awake conditions and modify their postural control accordingly. This investigation was prompted by the observation that previous studies had suggested that imagery of pain can elicit pain only in hypnotized Highs. The General Discussion presents hypotheses on structures and mechanisms possibly responsible for the observed effects. All together the results indicate that hypnotizability is a highly pervasive

trait modulating not only the subjective experience, through specific suggestions dissociating the latter from the real environmental and physiological conditions, but also modulating physiological functions, i.e. sensorimotor integration and autonomic control, even in the absence of suggestions and conditioning/expectations procedures. Thus, hypnotizability might become a model for advanced integrative approaches to cognitive science and, also, orient clinical trials for individualized neuro-rehabilitative treatments based on specific sensory stimulation and appropriate imagery training.

Sommario

La suscettibilità all'ipnosi è un tratto cognitivo multidimensionale che coinvolge, in particolare, le capacità attenzionali ed immaginative. Risultati precedenti hanno evidenziato differenze nell'integrazione sensorimotoria dipendenti dall'ipnotizzabilità, a livello di riflessi e di controllo posturale, anche in soggetti non ipnotizzati. Poichè il controllo posturale richiede una complessa integrazione sensorimotoria ed è modulato dall'attenzione, uno degli scopi (Parte 2) di questa tesi è stato di investigare gli effetti posturali dell'alterazione sensoriale (Studi 1 e 2) e del carico cognitivo (Studio 3), in soggetti con alti (Highs) e bassi (Lows) valori di ipnotizzabilità. I risultati hanno mostrato che Highs e Lows hanno un diverso set point per il controllo posturale, che gli input visivo e propriocettivo del collo e degli arti inferiori hanno una diversa rilevanza nella integrazione sensorimotoria richiesta e che le diverse risposte di Highs e Lows all'alterazione sensoriale non dipendono dalla disponibilità di risorse attentive. Poichè l'immaginazione ha mostrato un ruolo quasi percettivo negli Highs, l'altro scopo di questa tesi (Parte 3) è stato di investigare se l'immaginazione di anestesia riduca l'ampiezza del riflesso vestibolare e se l'immaginazione di testa ruotata ne cambi il piano preferenziale di oscillazione in modo diverso in Highs e Lows sottoposti a stimolazione galvanica vestibolare trans-mastoidea (Studio 4). Infatti, è noto che il riflesso vestibolare è scarsamente influenzabile dal controllo volontario e che la direzione della sua componente principale varia con la posizione della testa rispetto al tronco. I risultati hanno mostrato come un'elevata capacità immaginativa sia in grado di ridurre l'ampiezza del riflesso vestibolare, sia negli Highs che nei Lows, durante la suggestione di anestesia, mentre è necessaria un'elevata suscettibilità all'ipnosi per cambiare il piano di oscillazione durante l'immaginazione di testa ruotata. Questo potrebbe essere dovuto alla maggiore preferenza degli Highs per la modalità di immaginazione somestesica. Nello Studio 5, si è mostrato che gli Highs, ai quali sia stata somministrata la suggestione dolorosa, possono esperire dolore anche in condizioni di veglia e modificare di conseguenza il loro controllo posturale. Quest'ultimo studio è scaturito da studi precedenti che

suggerivano che l'immaginazione del dolore fosse sufficiente a suscitarlo solo in Highs ipnotizzati. La Discussione Generale presenta ipotesi su possibili strutture e meccanismi responsabili degli effetti osservati. Complessivamente i risultati indicano che l'ipnotizzabilità è un tratto altamente pervasivo, in grado di modulare non solo l'esperienza, attraverso specifiche suggestioni che la dissocino da ambiente e da stati soggettivi in corso, ma anche funzioni fisiologiche, come l'integrazione sensorimotoria e il controllo autonomico, anche in assenza di suggestioni e procedure di condizionamento e aspettativa. Per questo motivo quindi l'ipnotizzabilità potrebbe diventare un modello per un approccio integrativo avanzato alle scienze cognitive e, inoltre, orientare trial clinici per trattamenti neuro-riabilitativi personalizzati, basati su una specifica stimolazione sensoriale ed un training immaginativo appropriato.

Contents

Part I

General features

Introduction

The ability to enter the hypnotic state (Green et al., 2005) – which is defined hypnotizability or hypnotic susceptibility - is a multidimensional (Woody et al., 2005) cognitive trait evaluated by standard psychological instruments (scales) (Sheehan and McConkey, 1982; Weitzenhoffer, 1997). Indeed, hypnotizability includes various components, the most relevant being imagery (Crawford, 1982; Glisky et al., 1995; Lyons and Crawford, 1997; Kogon et al., 1998) and attention/ absorption abilities (Kallio et al., 2001; Tellegen and Atkinson, 1974; Crawford, 1989; 1994; Crawford et al., 1993). Traditionally, a peculiar characteristic of the supervisory attentional system, located in frontal lobes and in the limbic circuit, allowing a higher flexibility of the executive attentional control (Barber, 1960, Tellegen and Atkinson, 1974; Spiegel, 2003) has been considered responsible for the hypnotic behaviour (Norman and Shallice, 1986; Posner and Fan, 2004). More recent experimental findings (see Jamieson and Sheehan, 2004; Egner, et al., 2005) though, suggest a dissociated control of experience as the basis of hypnotic phenomena (Bowers, 1992; Woody and Bowers 1994; Kirsch and Lynn 1998; Comey and Kirsch, 1999). The ability of the highly hypnotizable individuals to accept hypnotic suggestions is attributed to a functional disconnection between the left dorsolateral prefrontal cortex and the anterior cingulus leading to an impairment of the frontal executive functions and to a diminished control of higher level activities on lower level cognitive systems. According to these views, the peculiar ability of "absorption" (deep involvement in mental images) exhibited by the subjects highly susceptible to hypnosis is no longer to be considered the consequence of a highly effective and flexible attentional control (Barber, 1960, Tellegen and Atkinson, 1974; Spiegel, 2003). On the contrary, it might be due to a failure in disengaging attention from its object (Jamieson and Sheehan, 2004). In these subjects, however, the hypnosis-related decoupling of executive functions may be efficaciously modulated by strategic attentional instructions (Raz et al., 2002; 2003). A suggestion of altered perception, administered to highly hypnotizable subjects, is associated with physiological/behavioural correlates characteristic of

the suggested perception. For instance, the instruction of analgesia is associated with a reduction of the amplitude of evoked potentials and of the activity in somatosensory areas (Crawford et al., 1998; Danziger et al., 1998; De Pascalis et al., 1999; Croft et al., 2002; De Pascalis et al., 2004a; Faymonville et al., 2006) as well as with modulation in the spinal nociceptive response (Kiernan et al., 1995; Danziger et al., 1998; Sandrini et al., 2000). As well as instructions of increased /decreased nystagmus (eyes' conjugate movement in the plane of body rotation) elicit congruent motor changes (Aschan et al., 1962), suggestions of movement or paralysis produce characteristic motor correlates (Roelofs et al., 2002; Blakemore et al., 2003; Ward et al., 2003), and the description of arm heaviness or rigidity is accompanied with arm lowering (Santarcangelo et al., 2005) and consistent changes in muscle activity (Winkel et al., 2006), respectively. Furthermore, even an implicit suggestion of backward falling, (that is a suggestion not describing the expected behaviour) produces a coherent body displacement (Carli et al., 2006). As a general rule, the physiological/behavioural effects of the suggestions are a function of the hypnotizability level, yet, although most studies concerning this topic have been performed during hypnosis, even in awake conditions and without specific suggestions, individuals with high (Highs) and low susceptibility to hypnosis (Lows) appear to differ in cognitive performances (Nordby et al. 1999; Jamieson and Sheehan 2002; Lichtenberg et al. 2004; Rubichi et al. 2005; Carli et al. 2007a; Carli et al. 2007b; Castellani et al. 2007) as well as in the somatic (Santarcangelo et al. 1989; 2003; Santarcangelo et al. 2004; 2008a) and autonomic responses during various tasks (Santarcangelo and Sebastiani 2004; Jambrik et al. 2004; Jambrik et al. 2005; Balocchi et al. 2005; Santarcangelo et al. 2008b). This is a novel perspective in the hypnosis field and there is now evidence that hypnotizability may account for a part of the physiological variability in the sensory-motor and autonomic domain.

Reflex responses modulation by hypnotizability

The importance of investigating the relationship between hypnotizability and motor responses (Santarcangelo et al., 1989, Busse, 1991 doctoral dissertation; Santarcangelo et al., 2003) arose from the observation that reflex motor responses are modulated (Grillon and Zarifian, 1985; Bonnet et al., 1995; Termos et al., 1997; Rossi-Durand, 2002) by cognitive/affective conditions and that different brain structures, like basal ganglia and cerebellum, are involved in both cognition and motor control (Georgopulos, 2000; Middleton and Strick, 2000; Serrien et al., 2007). The earliest observations

concern the elaboration of proprioceptive information in lower limbs. During a long-lasting relaxation session, the decrease of amplitude of the soleus muscle monosynaptic reflex (H reflex) (Hoffman, 1922), regularly elicited at a low frequency stimulation rate, occurred only in not hypnotized Highs (Santarcangelo et al., 1989). Different habituation characteristics of the H reflex in Highs and Lows might account for this result. In fact, H reflexes elicited pseudo randomly at higher frequencies, did not decrease their mean amplitude. However, as revealed by a time series analysis, only in Highs the H reflex amplitude depended on the amplitude of the H reflex occurring 3 intervals earlier in the stimulation series (Busse, 1991). All together, both results, the former concerning habituation occurring only in Highs and the latter suggesting a different "spinal memory" in the two groups, indicate a diverse elaboration of proprioceptive stimulation in Highs and Lows. The hypnotizability-dependent changes in H reflex amplitude might be influenced by motoneurones membrane excitability. Thus, as an index of the post-synaptic excitability, being due to a recurrent discharge of motoneurons activated antidromically and not dependent on proprioceptive stimulation, the F wave frequency of occurrence (Eccles, 1955) was studied. F waves (hardly elicitable in the soleus muscle) were elicited in the extensor muscles of both the feet (Carli and Santarcangelo, 2002) and the hands (Santarcangelo et al., 2003) because of the different supraspinal influences active on the respective motoneurone pools (Brower and Ashby, 1990), and on the two sides of the body because of a possible hypnotizability-related modulation due to the different involvement of the two cerebral hemispheres in hypnotic phenomena (Gruzelier, 1998). In the feet (muscle abductor allucis), no difference was found between Highs and Lows, suggesting that the H reflex modulation observed in Highs was due to pre-synaptic mechanisms not acting in Lows. In the hands (muscle extensor digiti minimi), a strong reduction of the frequency of occurrence of F waves indicated that the post-synaptic excitability decreased only in Highs and only on the right side. These findings indicate a different supraspinal control of motoneurone excitability in the two groups; indeed, during long-lasting relaxation sessions, only Highs exhibited inhibitory/disfacilitatory influences acting on the right upper limb extensor motoneurones post-synaptically (decreased F wave frequency of occurrence) and on both lower limbs extensor motoneurones pre-synaptically (decreased H reflex amplitude without changes in F wave).

Postural control modulation by hypnotizability - earlier findings

Vestibular input plays a major role in the control of posture (Diener et al., 1986; Horak and Hlavacka, 2001; Mergner et al., 2003; Basta et al., 2005). It is also involved in the appropriate representation of the body in space (Lackner and Di Zio, 2005; Angelaki and Cullen, 2008; Schautzer et al., 2003) and in the perception of body ownership (Lopez et al., 2008). Thus, a different weight of the vestibular information in the Highs' and Lows' central nervous system might be involved either in differences in sensori-motor integration or in proneness to out-of-body experiences, illusions, feeling-of-a-presence and other hallucinatory phenomena usually observed in Highs (Lopez et al., 2008). The neck proprioceptive input contributes to postural control. It interacts with vestibular signals providing appropriate information on the position of the head with respect to the trunk ((Nashner and Wolfson, 1974; Mergner et al., 1997; Manzoni, 2005). While the vestibulospinal reflexes evoked by labyrinthine, trans-mastoid, electrical stimulation (increasing and sinchronizing the firing of vestibular afferents (Goldberg et al., 1982; Emri et al., 2003; Latt et al., 2003; Nashner and Wolfson, 1974; Lund and Broberg, 1983), were similar in Highs and Lows, the global postural behaviour exhibited by the two groups depended on head position which modulated neck proprioceptive input (Santarcangelo et al., 2008a). In fact, the most reliable index of postural stability (Raymakers et al., 2005), mean Centre of Pressure (CoP, see Appendix A) velocity, increased during tonic head rotation only in Lows also in the absence of vestibular stimulation; in addition, larger changes of the mean position and of the area of the CoP displacement were observed in Highs, although not significant (Santarcangelo et al., 2008a). This suggested a possible easier integration of the vestibular and neck proprioceptive inputs (Lund and Broberg, 1983; Manzoni, 2005) in Highs and/or their higher proneness "to let themselves sway". On the contrary, Lows might be less compliant toward the postural unbalance due to head rotation and, thus, exhibit a more compelling need to re-adjust their body position (Carpenter et al., 2001; Adkin et al., 2002) and/or to increase the proprioceptive information arising from the legs, which can be obtained by increasing the sway mean velocity (Loram et al., 2005). In this case, the increase in velocity would represent a compensatory mechanism aimed at improving postural stability, rather than a mere consequence of a less efficient postural control. These observations were in line with the results of a study on the position of the trunk in Highs and Lows at the eyes closure. In the former, scarce changes in the trunk position were detected, while in the

latter a compensatory reaction consisting in a slight trunk rotation occurred, likely because eyes closure was more disturbing for Lows (Santarcangelo et al., 2004). A higher dependence of postural control on peripheral information in Lows (Carli et al. 2008) might account for these differences and might be due to different internal reference systems (Horak and Kuo 2000; Peterka and Loughlin 2004) operating in Highs and Lows.

Aim

The aim of this thesis was assessing the effects of both sensory alteration (Part 2) and of the imagery of it (Part 3) on the Highs' and Lows' postural control. In fact, attention has a role in both hypnotizability and postural control (see Carli et al., 2008) and imagery has been shown to elicit motor responses similar to those induced by real perception in Highs even if the subjects were unaware of the "appropriate" behaviour and experienced it as involuntary, as occurs when they receive suggestions not describing the expected response (Carli et al., 2006).

Methods

For all the studies described: 1) the experimental procedures followed the rules of the Declaration of Helsinki and all participants (healthy volunteers, age 18-32) signed an informed consent; 2) subjects underwent a preliminary neurological and orthopaedic evaluation at S. Chiara Hospital (Dr. Luca Bruschini); 3) hypnotizability was measured through the Italian version of the Stanford Hypnotic Susceptibility Scale, Form C (De Pascalis et al. 2000) and the percentage of highly susceptible subjects (Highs) found among the participants was in line with the distribution of hypnotizability generally observed (Balthazard and Woody 1989; De Pascalis et al. 2000; Carvalho et al. 2008; Santarcangelo et al., personal communication); 4) the participants stood barefoot on the stabilometric platform (NI-DAG 6.9.3, DUNE) with their heels 2 cm apart and their feet at an angle of 35°; 5) before any experimental procedure subjects were asked to fixate a point positioned 120 cm away from them at eye level; 6) the stabilometric variables (see Appendix A) provided by the platform software were: the area of the ellipse described by the movement of the centre of pressure (CoP) including 95% of the CoP positions (Area), the CoP mean velocity (Velocity) and the ratio between the length of the CoP trajectory and Area (length for surface, LFS). The analogue X-Y output from the platform was concomitantly acquired by a Labview system (sample rate 2 KHz) and the decimated (sample rate: 100 Hz), digitized signals were stored for subsequent analysis.

Part II

Hypnotizability, attention and posture

Study 1 - Suppression of vision and alteration of the leg proprioceptive input

Body sway of highly hypnotizable subjects might be less affected by sensory alteration, with respect to Lows. In fact, attention has a role in both hypnotizability and postural control. The latter is an "attention consuming" function modulated by expectation (Caudron et al. 2008), the subject's intention to respond to postural disturbance with a specific strategy (see Jacobs and Horak 2007) and concomitant mental activities (Balasubramaniam and Wing 2002; Woollacott and Shumway-Cook 2002; Vuillerme and Vincent 2006; Fraizer and Mitra, 2008). On the other side, the attentional cost of balance, expressed by longer reaction times to concomitant cognitive tasks, is proportional to the difficulty of the postural condition and to the individual postural expertise (Vuillerme and Nougier 2004), and is increased by sensory alteration experimentally induced (see Santarcangelo et al. 2004) or due to age and pathology (Horak and Hlavacka 2001; Shaffer and Harrison 2007; Dieterich 2007). Greater availability of attentional resources in Highs might account for the observation that body sway is modified in Lows, but not in Highs, during guided imagery and mental computation (Carli et al. 2007); it might also lead to lower vulnerability of the body sway to sensory alteration in Highs. The aim of the present experiment was to investigate, in Highs and Lows, the postural effects of the suppression of visual input and of the alteration of leg proprioceptive information.

Methods

Subjects

Subjects were divided into 2 groups: 10 subjects with high hypnotic susceptibility (Highs, SHSS score, $mean \pm SE$, 9.8 ± 0.36, 6 females) and 12

with low hypnotic susceptibility (Lows, SHSS score, 0.33 ± 0.22, 6 females). Height ($mean \pm SE(cm)$. Highs, 173.60 ± 3.04; Lows, 169.91 ± 2.01), weight ($mean \pm SE(kg)$. Highs, 66.80 ± 3.66; Lows, 63.67 ± 2.37) and foot size (shoe size, $mean \pm SE$. Highs, 41.8 ± 1.06; Lows, 40.67 ± 0.71) were similar in Highs and Lows.

Experimental procedure

The experimental protocol involved 2 Conditions (*firm*: stable support; *foam*: unstable support due to interposition of an 8 cm thick piece of foam between the feet and the platform). In each Condition, the subjects performed 3 Trials (I, II, III) separated by 2-3 minutes of rest in sitting position, consisting of a sequence of 2 periods corresponding to 2 Eyes conditions (Eyes): open (OE, 1 min) and closed eyes (CE, 1 min). During OE, the subjects were asked to fixate a point positioned 120 cm away from them at eye level. At the beginning of the experiment (*firm* condition, open eyes, feet in the same position as during the experiment), all subjects reported perceiving themselves as absolutely stable and scored their sway as 1 (score of sway perception range: min 1- max 10). At the end of each trial, the subjects were interviewed about their perception of sway during OE and CE with respect to the initial evaluation. In fact, healthy subjects can reliably evaluate their body sway (Schieppati et al., 1999). The analogue X-Y output from the platform concomitantly acquired by a Labview system were stored for subsequent stabilogram diffusion analysis (SDA) (Collins and De Luca 1993), which accords with the inverted pendulum model (Horak and McPherson, 1996; Gage et al., 2004) and allows identifying the coordinates of the critical point and the slopes of the fitting lines of the mean square CoP displacements, in the frontal and sagittal planes. The critical point is the point where and when the shift from the central controlled system occurs (Fig. 1) (see Appendix B).

Data analysis

The scores of the subjective perception of sway, the stabilometric variables (Area, Velocity, LFS) and the SDA parameters (critical point coordinates in the frontal and sagittal planes: abscissa (t_x, t_y), ordinate (x, y); regression line slopes: ($shortX, longX, shortY, longY$) were analyzed by separate repeated measures ANOVA following a 2 Groups (Highs, Lows) x 2 Conditions (*firm*, *foam*) x 3 Trials (I, II, III) x 2 Eyes conditions (OE, CE) design. Contrast analysis and t-test were performed when appropriate. The level of significance was set at $p < 0.05$. Statistics is reported in the text and

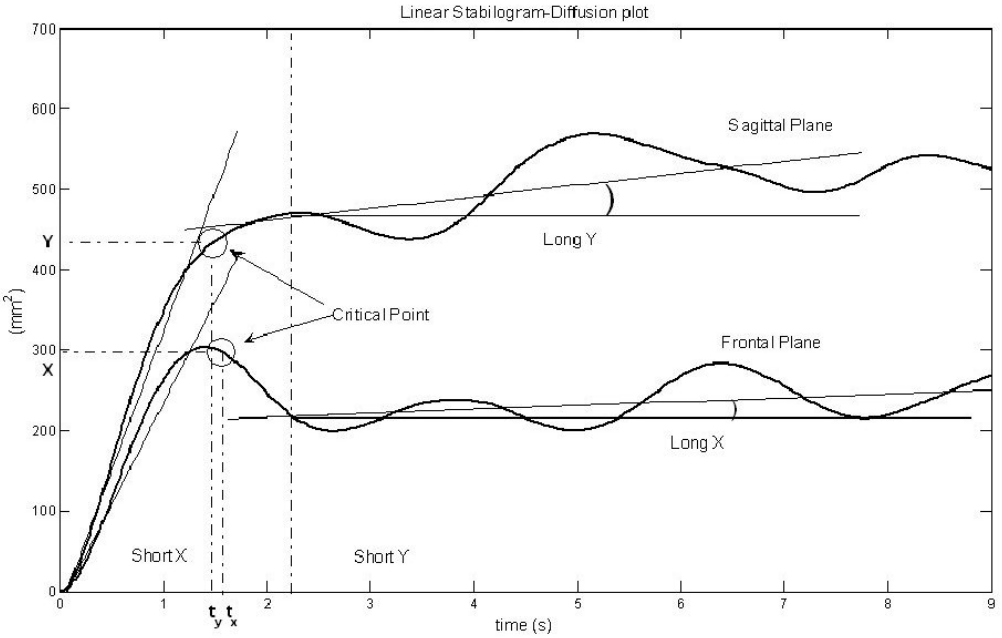

Figure 1: Stabilogram Diffusion Analysis identifies two different mechanisms in posture control for Short and Long term. Characterizing parameters are: the Critical Point coordinates, where the open loop, short term, control shifts to closed loop, long term, and the slopes of the regression lines in short and long term.

partially shown in figures. ANOVA tables summarizing all significant results appear in Appendix C.

Results

The description of the results will focus on the differences between Highs and Lows. Thus, main effects and interactions not involving the Group factor will not be extensively described.

Subjective experience of sway

ANOVA did not reveal any difference between Highs and Lows in sway perception. Both groups perceived a significantly larger sway at eyes closure ($F(1,20)=162.749$, $p < 0.0001$; mean + SE. OE: Highs, $3.23 + 0.30$; Lows, $2.95 + 0.29$; CE: Highs, $5.88 + 0.52$; Lows, $4.98 + 0.50$) and on the unstable

Group			Highs		Lows	
Variable	Support	Eyes	Mean	SE	Mean	SE
Velocity	*firm*	OE	7.73	0.76	7.82	0.70
(mm/sec)		CE	12.17	1.19	10.26	1.09
	foam	OE	16.55	1.16	14.16	1.06
		CE	28.97	2.06	22.84	1.88
Area	*firm*	OE	300.77	48.75	248.81	44.50
(mm^2)		CE	473.77	67.70	251.28	61.80
	foam	OE	1096.23	141.26	557.39	128.95
		CE	1749.57	199.52	712.94	182.14
LFS	*firm*	OE	0.84	0.07	0.89	0.06
$(1/mm)$		CE	0.97	0.09	1.03	0.09
	foam	OE	0.87	0.10	1.07	0.09
		CE	1.06	0.13	1.62	0.12

Table 1: Mean values of the stabilometric variables averaged across Trials

support (F(1,20)=138.620, $p < 0.0001$; firm: Highs, 2.89 + 0.30; Lows, 2.33 + 0.29; foam: Highs, 6.22 + 0.58; Lows, 5.61 + 0.55). The perception of greater sway in the foam condition concerned all Trials (T1: t(1,21)=8.567, T2: t(1,21)=9.107, T3: t(1,21)=5.153; $p < 0.0001$) and both Eyes conditions (OE: (t(1,21)=8.567, CE: (t(1,21)=7.556; $p < 0.0001$).

Body sway: Stabilometric variables

Velocity

Significant increases in velocity occurred in both groups at eyes closure ($F(1, 20) = 141.91, p < 0.0001$). The significant Eyes x Group interaction ($F(1, 20) = 5.93, p < 0.05$) revealed that the CoP mean Velocity was similar in the two groups during OE, but significantly higher in Highs than in Lows during CE ($t(1, 20) = 2.243, p < 0.05$) (Fig 2 A), which indicates that it increased in Highs more than in Lows. Decomposition of the significant Trial x Eyes x Group interaction ($F(2, 40) = 3.37, p < 0.05$) showed that Velocity increased during CE in both groups for all Trials (Fig. 2 B), but more in Highs than in Lows for Trials II ($t(1, 20) = 2.838, p < 0.05$) and III ($t(1, 20) = 2.978, p < 0.01$). Perhaps, Lows "learned" how to manage sensory alteration after T1 and exhibited smaller Velocity increases for T2 and T3 with respect to T1, whereas Highs did not change their response to eye closure across Trials (Fig.2).

Table 1 reports the Velocity, Area and LFS values averaged across Trials

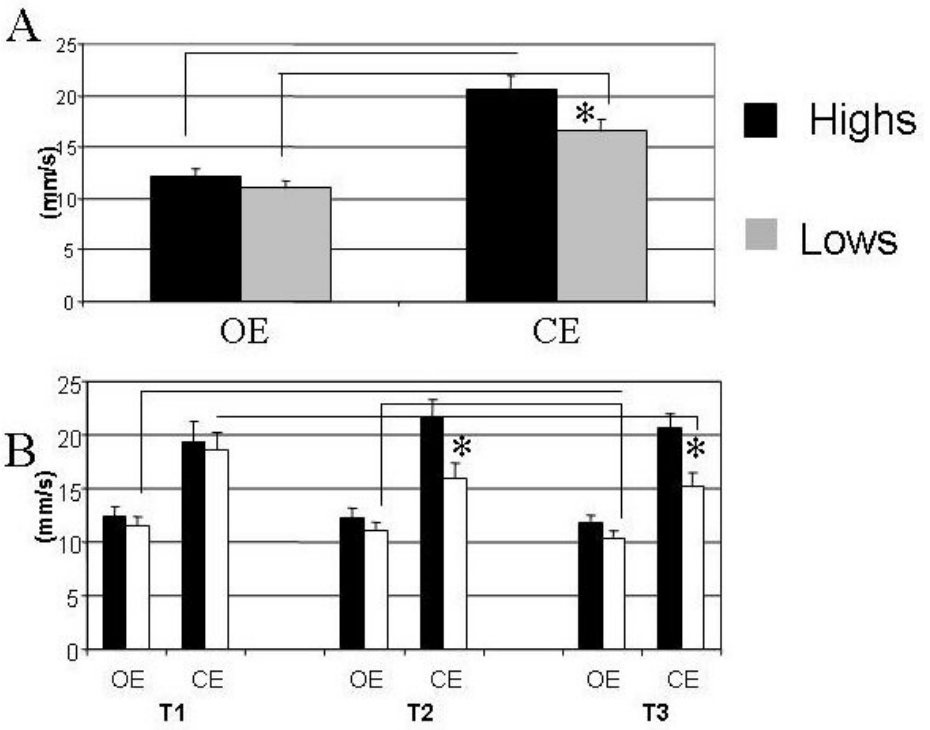

Figure 2: CoP Velocity, A Eyes x Group interaction, B Trial x Eyes x Group interaction, line = between condition significant difference, *= between groups significant difference, OE=Open Eyes, CE=Closed Eyes, T1, T2, T3 = Trials.

$(mean + SE)$ in the *firm* and *foam* conditions during OE and CE.

Both Highs and Lows increased Velocity in foam with respect to firm ($F(1, 20) = 118.83$, $p < 0.0001$). No interaction between hypnotizability and the effects of alteration of leg proprioceptive input was observed.

Area

ANOVA revealed that Area was generally higher in Highs than in Lows (F(1,20)=13.162, $p < 0.001$) and the former changed their Area more than the latter. In fact, decomposition of the significant Condition x Trial x Eyes x Group interaction ($F(1, 20) = 4.877, p < 0.05$) indicated that during CE Highs increased Area for T3 in *firm* (Fig. 3 A) and for all Trials in *foam* (Fig. 3 B), while Lows increased Area only in *foam* and only for T3 (Fig. 3 B). These changes correspond to significantly higher Area values in Highs

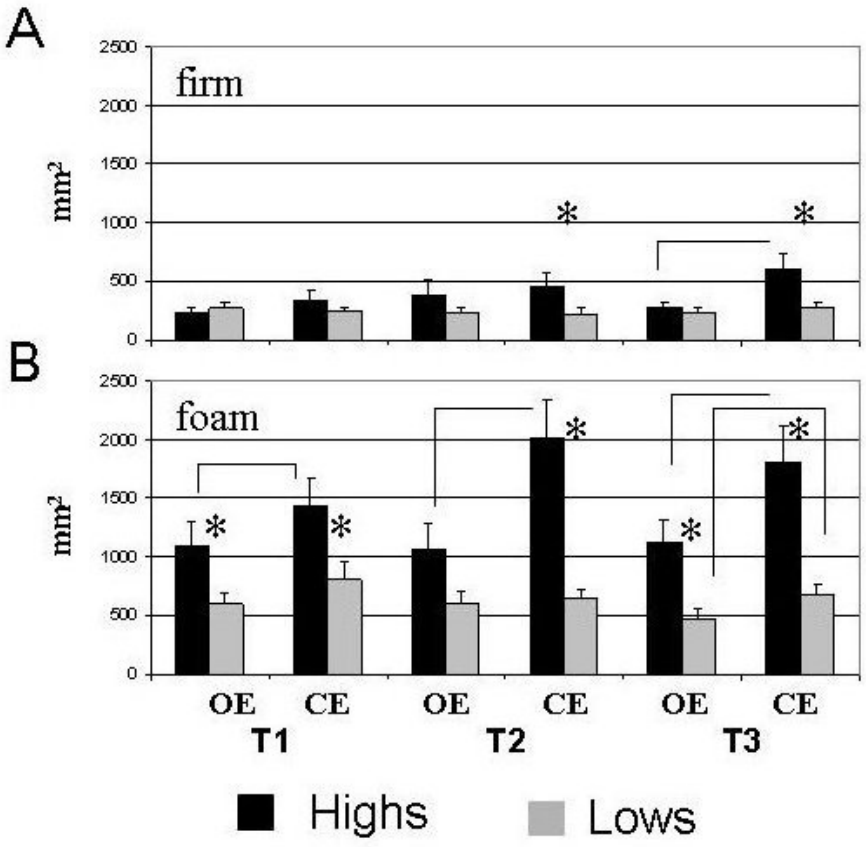

Figure 3: CoP Area, Condition x Trial x Eyes x Group interaction, A *firm* Condition, B *foam* Condition, line = between condition significant difference, *= between groups significant difference, OE=Open Eyes, CE=Closed Eyes, T1, T2, T3 = Trials.

than in Lows during CE (for T2 and T3) in firm (Fig.3 A) and during both OE (for T1 and T3) and CE (for all Trials) in *foam* (Fig. 3 B).

LFS

Decomposition of the significant Condition x Eyes x Group interaction ($F(1,20) = 6.553, p < 0.05$) showed that LFS (Fig. II A) increased in both groups at eyes closure in *firm* (Highs: $F(11,9) = 5.256$, $p < 0.05$; Lows: $F(1,11) = 24.678$, $p < 0.001$) but only in Lows in foam ($F(1,11) = 33.93, p < 0.0001$). Thus, Highs had significantly lower LFS values than Lows in *foam* during CE ($t(1,20) = 3.062, p < 0.05$). In addition, decomposition of the significant Condition x Trial x Eyes x Group interaction ($F(2,40) = 4.707, p < 0.05$) indicated that in Highs there was no significant change in LFS across Trials in both *firm* and *foam* conditions; in contrast, Lows showed lower LFS values in T2 and T3 than in T1 in *firm* (Fig. II B), which indicates a learning behaviour in this condition. In the *foam* condition, they did not show any change in the effects of eyes closure across Trials and LFS increased in T3 with respect to T2 during OE (Fig. II C). As a result, the LFS values in Lows were lower in *firm* than in *foam* during OE for T3 and during CE for all trials (Fig.II). In summary, the stabilometric variables showed that 1) suppression of visual input increases the CoP mean Velocity in Highs more than in Lows, while alteration of leg proprioceptive input increases it similarly in the two groups; 2) suppression of visual input increases Area only in Highs on the stable support, but in both groups in the unstable condition; alteration of leg proprioceptive input increases it in both groups, but more in Highs than in Lows; 3) suppression of visual input increases LFS similarly in the two groups, while alteration of leg proprioceptive input induces different postural strategies because it increases LFS only in Lows. If in two different conditions /groups a similar Area is described by the CoP movement and LFS is larger in one of them, in that condition the CoP trajectory is longer than in the former due to a larger number of shorter oscillations. Finally, only Lows show learning behaviour across Trials concerning Velocity and LFS.

Body sway: Stabilogram diffusion analysis

Table 2 reports the values of the coordinates of the critical point and of the slopes of the diffusion coefficient regression lines (see Fig.1) averaged across Trials (mean + SE). Critical point coordinates. Hypnotizability did not affect the abscissa of the critical point. In both groups, it was larger in *firm* than in *foam* in the frontal ($F(1,20) = 8.084, p < 0.01$) and sagittal plane

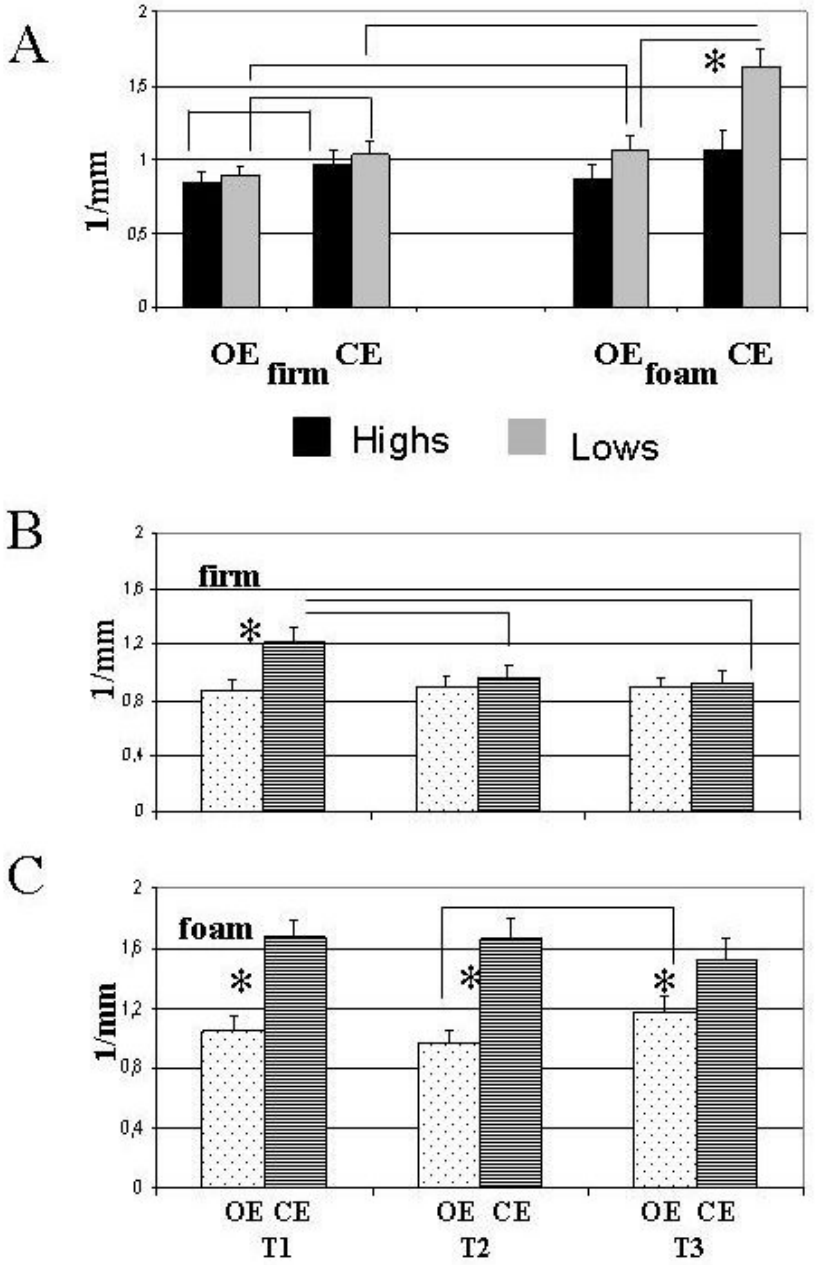

Figure 4: LFS, A Condition x Eyes x Group interaction, B Condition x Trial x Eyes x Group, *firm* condition, C *foam* condition, line = between condition significant difference, *= between groups significant difference, OE=Open Eyes, CE=Closed Eyes, T1, T2, T3 = Trials.

Plane			**Frontal**				**Sagittal**			
variable	**condition**	**eyes**	**Highs**		**Lows**		**Highs**		**Lows**	
critical point			mean	SE	mean	SE	mean	SE	mean	SE
abscissa	*firm*	OE	1.73	0.13	1.47	0.12	1.40	0.11	1.30	0.10
(sec)		CE	1.54	0.13	1.54	0.12	1.60	0.12	1.47	0.11
	foam	OE	1.41	0.11	1.36	0.10	1.31	0.09	1.09	0.08
		CE	1.36	0.07	1.23	0.06	1.44	0.10	1.16	0.09
ordinate	*firm*	OE	14.00	2.47	10.30	2.25	24.56	5.32	15.71	4.86
(mm^2)		CE	65.42	25.03	17.16	22.85	72.47	13.07	31.57	11.93
	foam	OE	63.57	7.71	29.07	7.04	91.18	12.52	42.25	11.43
		CE	172.60	26.20	57.69	23.92	334.50	53.98	108.05	49.28
slopes			mean	SE	mean	SE	mean	SE	mean	SE
$(a.u)$	*firm*	OE	5.71	1.15	5.44	1.05	10.45	2.02	8.26	1.84
short period		CE	25.34	9.28	8.20	8.47	26.78	4.18	14.39	3.82
	foam	OE	26.33	3.07	16.74	2.80	47.14	6.88	31.81	6.28
		CE	87.16	12.81	39.88	11.70	132.15	19.34	76.07	17.65
	firm	OE	0.734	0.183	0.5516	0.167	3.60	1.02	2.44	0.93
long period		CE	0.2337	0.309	0.4584	0.282	2.49	1.13	1.39	1.03
	foam	OE	2.8018	0.499	1.1503	0.455	13.03	2.83	4.83	2.59
		CE	0.8202	0.469	0.6437	0.428	1.72	1.63	1.61	1.49

Table 2: Stabilogram diffusion analysis: mean values of the critical point coordinates and of the slopes of the diffusion coefficients regression lines averaged across Trials

($F(1,20) = 6.323, p < 0.05$), while it was significantly larger during CE than during OE only in the sagittal plane ($F(1,20) = 12.354, p < 0.01$). In the frontal plane, the ordinate of the critical point increased significantly in *foam* ($F(1,20) = 22.881, p < 0.001$) and during CE ($F(1,20) = 14.039, p < 0.001$). ANOVA revealed significant Group x Condition ($F(1,20) = 4.655, p < 0.05$) and Group x Eyes ($F(1,20) = 5.713, p < 0.05$) interactions. The former indicated higher values of the ordinate in *foam* than in *firm* in both groups (Highs, $F(1,9) = 11.070, p < 0.01$; Lows, $F(1,11) = 20.368, p < 0.0001$) and higher values in Highs than in Lows in *foam* ($t(1,20) = 3.395, p < 0.01$). The latter showed higher values during CE than during OE in both groups (Highs, $F(1,9) = 7.991, p < 0.05$; Lows, $F(1,11) = 19.946, p < 0.001$), although changes were apparently larger in Highs (Tab.2). The critical point ordinate was significantly greater in Highs than in Lows during both conditions (OE: $t(1,20) = 3.325, p < 0.01$; CE: $t(1,20) = 2.817, p < 0.05$). Also in the sagittal plane the ordinate was larger in Highs than in Lows ($F(1,20) = 11.881, p < 0.001$). However, the significant Condition x Eyes x Group interaction ($F(1,20) = 5.380, p < 0.0$) revealed that the critical point ordinate was larger in Highs than in Lows during both OE ($t(1,20) = 2.886, p < 0.01$) and CE ($t(1,20) = 3.098, p < 0.01$) in *foam*, but only during CE in *firm* ($t(1,20) = 2.311, p < 0.05$). Slopes of the diffusion coefficient regression lines. In the frontal plane, the significant Group effect showed that the regression line slope for the short-term control period was generally higher in Highs than in Lows ($F(1,20) = 6.684, p < 0.05$). It increased significantly in both groups at eyes closure ($F(1,20) = 20.105, p < 0.0001$) and on the unstable support ($F(1,20) = 44.934, p < 0.0001$), but the significant Eyes x Group interaction ($F(1,20 = 5.288, p < 0.05$) showed that the slope was quasi significantly higher in Highs than in Lows only during OE ($t(1,20) = 2.062, p = 0.052$), while the significant Condition x Group interaction ($F(1,20) = 4.394, p < 0.05$) indicated that in *foam* the slopes were larger in Highs than in Lows ($t(1,20) = 2.780, p < 0.05$). In the long-term control period, both groups increased their regression line slope in *foam* ($F(1,20) = 9.375, p < 0.01$) and decreased it during CE ($F(1,20) = 12.22, p < 0.01$). However, according to the significant Eyes x Group interaction ($F(1,20) = 4.559, p < 0.05$), the decrease during CE was significant only in Highs ($F(1,9) = 9.553, p < 0.001$) and significantly higher slopes in Highs than in Lows were only observed during OE ($t(1,20) = 2.401, p < 0.05$). In the sagittal plane, the slopes of the short-term regression lines were higher in Highs than in Lows ($F(1,20) = 5.409, p < 0.001$), but the Eyes x Group interaction ($F(1,20) = 5.301, p < 0.05$) indicated that this difference was significant only during CE ($t(1,20) = 2.420, p < 0.05$). The slopes of the long-term regression lines were not affected by eyes closure and increased

significantly in *foam* ($F(1,20) = 20.368, p < 0.0001$), but the significant Condition x Group interaction ($F(1,20) = 5.877, p < 0.05$) showed that the increase was significant only in Highs ($F(1,9) = 14.237, p < 0.001$) whose values became higher than the Lows' ones in *foam* ($t(1,20) = 2.195, p < 0.05$).

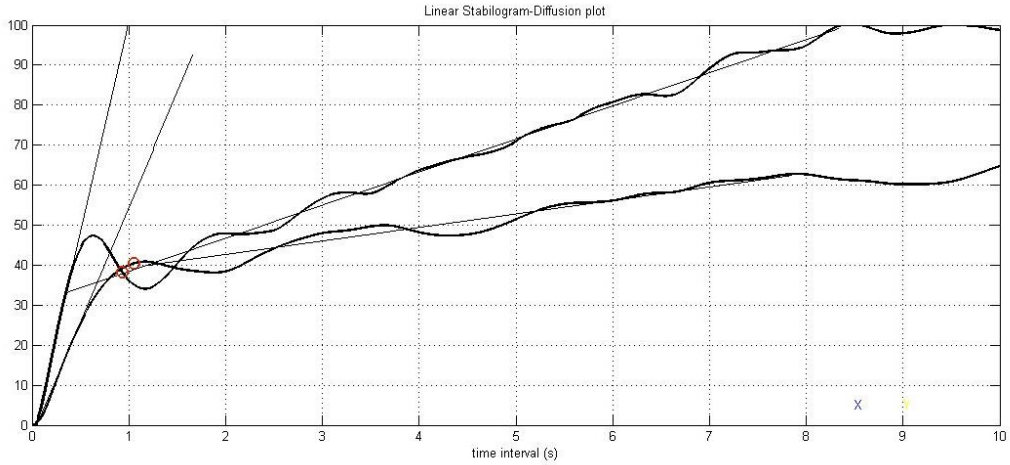

Figure 5: Highly hypnotizable representative subject, red circles=Critical point in Frontal and Sagittal planes, lines on the left of the Critical point: short term response, lines on the right: long term response

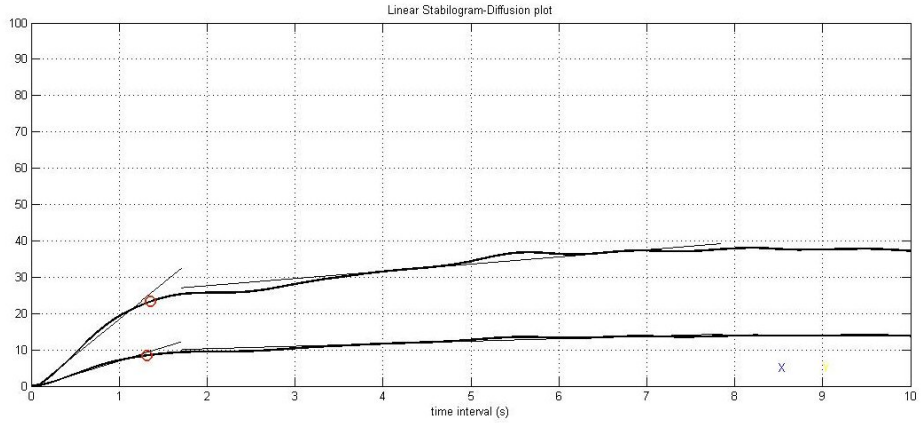

Figure 6: Low hypnotizable representative subject, red circles = Critical point in Frontal and Sagittal planes, lines on the left of the Critical point: short term response, lines on the right: long term response

In summary, differences between Highs and Lows in the changes in the critical point ordinate and in the slopes of the diffusion coefficient regression

lines were found in both planes for both sensory alteration (Fig. 5, 6), although suppression of visual input induces minor differences with respect to proprioceptive disturbance. The generally higher critical point ordinate and slopes of the short-term diffusion coefficient regression lines in Highs (Fig.5) indicate that their CoP can assume a wider range of positions with respect to Lows (Fig.6) before the occurrence of feed-back control mechanisms.

Discussion

The results support the hypothesis that hypnotizability modulates the postural effects of visual and proprioceptive alteration and that Highs and Lows exhibit different postural control (point 1). The changes induced in the stabilometric variables by sensory alteration do not confirm the hypothesis of greater stability of Highs. However, the stabilogram diffusion analysis suggests that Highs have a wider range of stable positions and that different internal reference systems might account for both this and the similar subjective perception of sway associated with different actual sway in Highs and Lows (point 2). The findings concerning higher CoP displacements in Highs before their shift from a centrally to a peripherally controlled model of the CoP movement are in line with the original observations by Collins and De Luca (1993) who identified two different populations of subjects on the basis of the coordinates of the critical point (see Appendix B). The smallest population had wider range of CoP oscillations before the shift, which is what can be observed when subjects are divided in Highs and Lows (Balthazard and Woody 1989; De Pascalis et al. 2000; Carvalho et al. 2008; Santarcangelo et al, unpublished observation) . As for point 1, the results show that the CoP movement has a similar area and mean velocity in Highs and Lows on a normal support with the eyes open, but it becomes larger and faster in Highs when the visual input is suppressed and/or the support becomes unstable, in spite of the lack of any difference between Highs and Lows in the perception of sway. Nonetheless, the changes in the length/surface ratio (LFS) of the CoP trajectory indicate that suppression of the visual input induces similar postural strategies in the two groups, while alteration of the leg proprioceptive input increases LFS only in Lows. This suggests that the latter are more dependent than Highs on accurate proprioceptive monitoring and attain stability via mechanisms aimed at increasing/ improving the impaired proprioceptive information (Loram et al. 2005). In fact, the two groups show similar increases in CoP mean velocity, while Highs increase Area much more than Lows, which suggests that Lows perform a higher number of shorter oscillations than Highs , Eye closure also affects the stabilometric variables

more in Highs than in Lows, since the CoP mean velocity, considered the most appropriate index of postural stability in most situations (Jeka et al. 2004; Raymakers et al. 2005), increases more in the former than in the latter. However, unlike proprioceptive alteration, it does not elicit different postural strategies in the two groups; thus, it seems to induce only minor differences between Highs and Lows with respect to proprioceptive alteration. The effects of eyes closure observed in the present study cannot be compared with previous results concerning the mean position and maximum displacement of acromia, back joints, iliac spines and knees (Santarcangelo et al. 2004). In that experiment, the variables were different, the participants maintained a less stable foot position (feet together) and the fixation point was at a longer distance from the subjects' eyes. Moreover, slight changes in the maximum displacement of one acromion do not necessarily affect the CoP movement. Stabilogram diffusion analysis allows interpreting the differences observed between Highs and Lows on the basis of a pre-eminent centrally-driven postural control in Highs (point 2) and suggests that Highs and Lows differ in their reference systems for postural control. Indeed, the point "where and when" the control shifts from central to feedback mechanisms (Collins and De Luca, 1993) is different in the two groups and corresponds to longer CoP trajectories in Highs than in Lows, suggesting that Highs can manage their postural control without feedback mechanisms, i.e. independently of the availability of sensory information, in a wider range of CoP displacements with respect to Lows. In terms of the feed-back controlled, inverted pendulum model (see Methods), the "integral" term of the controller system (Peterka 2000) is apparently pre-eminent in Highs and the "derivative" term in Lows, the former showing larger overshoot and the latter more efficient damping with respect to the set point (see Appendix B). Thus, different set points and control mechanisms operate in the two groups in response to both visual suppression and proprioceptive disturbance, although the former seems to be more easily compensated than the latter in both groups. The present findings suggest that the hypothesis of lower vulnerability of Highs to the effects of sensory alteration (not supported by the analysis of the stabilometric variables) should give way to the hypothesis of a different kind of stability in Highs and Lows, as indicated by the stabilogram diffusion analysis. Indeed, Highs have a wider range of centre of pressure positions subjectively experienced as stable when vision is occluded and/or proprioception is impaired, and according to the results of SDA, these positions are also recognized as stable by the internal reference system. Yet, models different from the inverted pendulum show that changes in the direction of the CoP motion within the stability region, instead of the location of the CoP within it, might better account for postural responses to sensory alteration (Haibach et al., 2007) and indicate a

flexibility in control strategies not detectable through stabilogram diffusion analysis, which cannot identify the time evolutionary properties of the centre of pressure dynamics (Newell et al., 1997). This point of view would further emphasize the relevance of the higher ratio between the CoP trajectory and area observed in Lows with respect to Highs during proprioceptive alteration. In addition, a few indexes derived from these dynamic models have been associated with EEG patterns apparently predictive of instability (Slobounov et al., 2009), which might be particularly relevant in the interpretation of the differences between Highs and Lows in the response to sensory alteration. Indeed, the results seem to indicate that Highs have a lower need for body sway corrections. This might be due to a pre-eminent centrally-driven control or to a greater ability to re-weight vestibular signals when somatosensory cues from the support surface are disrupted (Horak and Hlavacka, 2001), as occurs in gymnasts who do not show lower CoP displacements although they exhibit higher stability of their head position during various postural tasks (Gauthier et al. 2007). It is also possible that the integration of various sensory sources in building up an "internal representation" of the body and of its motion in space - an internal model (Wolpert and Miall 1996) - is more effective in Highs and makes them able to manage sensory alteration satisfactorily in spite of greater changes in the area and velocity of CoP movement. From this point of view, the similar subjective perception of sway associated with different actual sway in the two groups might be due to different results of the comparison between the actual sway and the range of stable positions determined by their internal models. In conclusion, the results of this study indicate a role of hypnotizability in the development of adaptive strategies and a high pervasiveness of the hypnotic trait which might influence not only the way the environment is imagined (Carli et al. 2007a; b) but also how it is physically experienced.

(Data published in Exp Brain Res, 191:331-40, 2008)

Study 2 - Bilateral impairment of vestibular input

Besides visual and proprioceptive/tactile information, vestibular input plays a major role in the control of posture (Diener et al., 1986; Horak et al, 2001; Mergner et al, 2003; Basta et al., 2005). It is also involved in the appropriate representation of the body in space (Lackner and Di Zio, 2005; Angelaki and Cullen, 2008; Schautzer et al., 2003) and in the perception of body ownership (Lopez et al., 2008). Thus, a different weight of the vestibular information in the Highs' and Lows' central nervous system might be involved either in differences in sensori-motor integration or in proneness to out-of-body experiences, illusions, feeling-of-a-presence and other hallucinatory phenomena usually observed in Highs (Lopez et al., 2008). Yet, vestibulospinal reflexes elicited by labirinthine galvanic stimulation were found similar in Highs and Lows (Santarcangelo et al., 2008a), while the effects of tonic alteration of the vestibular information on posture and gait have not been studied. Aim of the present study was to investigate postural control during bilateral alteration of the vestibular input obtained through backward head extension which degrades vestibular information due to the disadvantageous position of the utricular otoliths (Jackson and Epstein, 1991).

Methods

Subjects

The participants were 11 Highs (SHSS $score > 9/12$) and 11 Lows (SHSS $score < 3/12$) . Height ($mean \pm SE(cm)$. Highs, $169.73 \pm 2..84$; Lows, 170.56 ± 1.25), weight ($mean + SE(kg)$. Highs, 63.910 ± 2.45; Lows, 65.67 ± 2.37) and foot size (shoe size, $mean \pm SE$. Highs, 40.64 ± 1.02; Lows, 40.89 ± 0.67) were similar in Highs and Lows.

Experimental procedure

Eleven Highs (6 females) and 11 Lows (5 females) not aware of the aims of the study joined an experimental session performed with eyes closed and including 2 head positions (head forward, *basal*; backward extended head, *BEH*) lasting 1min each in 2 postural conditions *firm* and *foam* (stable and unstable support respectively). Head extension was about 45°. Instability of the support was obtained through interposition of an 8 cm thick foam between feet and platform. Before closing their eyes, subjects were asked to score their perception of sway, all of them scored it 1 (score range: 1- 10). After eyes closure, they had to evaluate their sway at the end of basal and BEH conditions in both postural conditions (*firm* and *foam*).

Data analysis

The scores of the subjective perception of sway and the stabilometric variables (Area, Velocity) underwent separate repeated measures ANOVAs following to a 2 Groups (Highs, Lows) x 2 Support conditions (*firm*, *foam*) x 2 Head positions (basal, BEH) design. The Greenhouse-Geisser ϵ correction was applied when appropriate. Level of significance was set at $p < 0.05$.

Results

The perception of sway amplitude during BEH was similar in Highs and Lows. The significant Head x Support interaction ($F(1,20) = 7.365, p < 0.013$) indicated a higher perception of sway during BEH than during basal conditions only on the unstable support ($t(1,21) = 6.750, p < 0.0001$). In the frontal plane, backward head extension did not modify the CoP mean position which, instead, was significantly displaced toward the right side by the unstable support, independently of head position ($F(1,20) = 18.321, p < 0.0001$). In the sagittal plane, the CoP position was anteriorly displaced by both the unstable support ($F(1,20) = 54.951, p < 0.0001$) and backward extension of the head ($F(1,20) = 11.292, p < 0.003$). A significant Support effect was observed for both CoP Velocity ($F(1,20) = 97.99, p < 0.0001$) and Area ($F(1,20) = 35.66, p < 0.0001$) which increased significantly also during BEH in both groups (Velocity, $F(1,20) = 32.893$; Area, $F(1,20) = 21.156$; $p < 0.0001$). Significant Support x Head interactions were observed (Velocity, $F(1,20) = 12.366, p < 0.002$; Area, $F(1,20) = 6.948, p < 0.016$), but they were not sustained by significant contrasts (Fig. 7 A, B) Although significant Group effects and interactions were not observed, in line with previous findings (Study 1; Santarcangelo et al, 2008b) the Highs' sway area

tended to be larger than the Lows' one ($F(1,20) = 3.432, p = 0.079$). This was more apparent during backward head extension on the unstable support ($t(1,20) = 2.020, p = 0.057$).

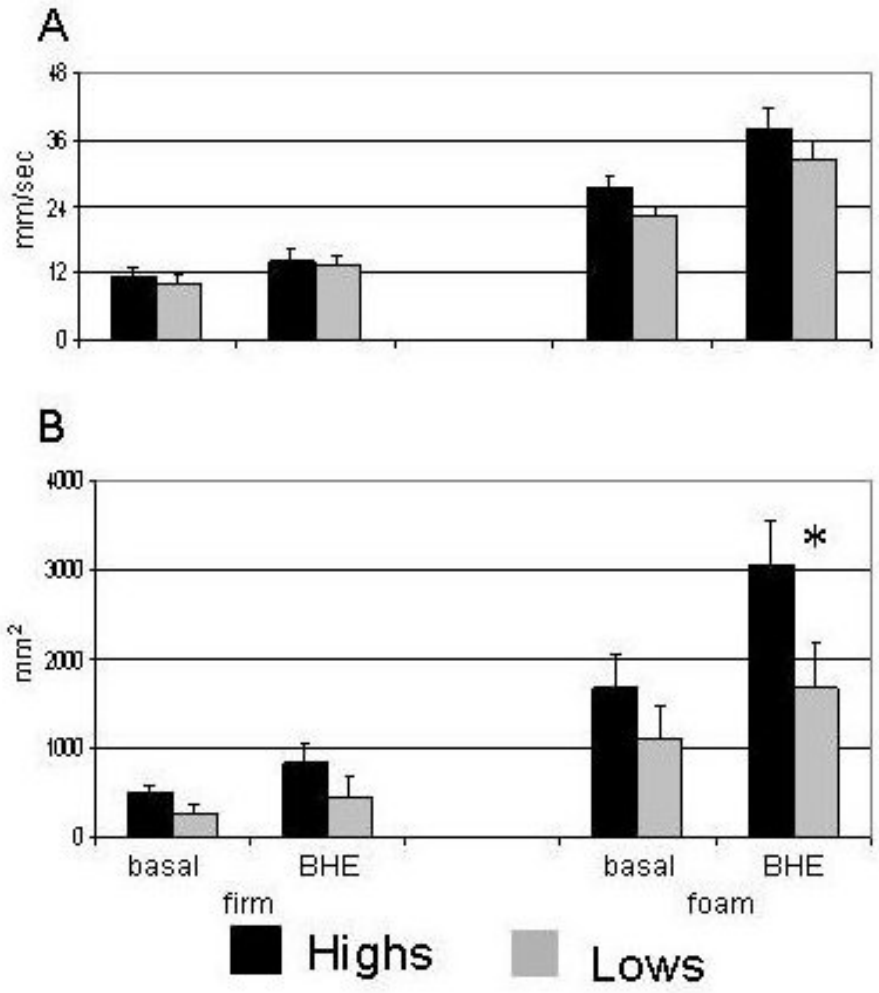

Figure 7: Support x Head x Group interaction, A CoP velocity, B CoP Area, BHE Backward Extended Head, * = between groups quasi significant difference.

Discussion

At variance with visual and leg/neck proprioceptive alteration (Study 1; Santarcangelo et al., 2008a, b), the partial impairment of vestibular information was similarly experienced by Highs and Lows and did not induce major differences in their body sway. The increased instability observed during head extension in both groups (higher CoP velocity, larger CoP area) confirms the results obtained in subjects not selected for hypnotizability (Jackson and Epstein, 1991; Horak and Hlavacka, 2001; Horak et al., 2001; Paloski et al., 2006; Pinsault and Vuillerme, 2008). The increased perception of instability during head extension observed only on the unstable support is in line with the higher requirement of vestibular information described during alteration of the leg proprioceptive input in blindfolded individuals (Pinsault and Vuillerme, 2008) and highlights the role of multisensory integration in both motor control and perception of motion (Lackner and Di Zio, 2005; Angelaki and Cullen, 2008). As the various sensory inputs – visual, vestibular, proprioceptive - display partially hypnotizability-dependent relevance in the control of posture (Study 1 and 2), these observations raise an interest into a possible role of hypnotizability as a factor influencing the construction of the individual sensori-motor "self". The hypothesis that humans may differ between each other in the responsivity to/reliance on/tolerance of the alteration of the various sensory modalities is supported by the occurrence of different modes of sensory- motor integration recently suggested in animals, as the activity of rotation-responsive vestibular nuclei neurons is modulated by both vestibular and neck proprioceptive inputs in the squirrel monkey (Gdowski and McCrea, 2000), but only by vestibular stimulation in the rhesus monkey (Roy and Cullen, 2001). The authors suggest that this difference might have been developed in order to comply with arboreal or terrestrial habitat, although, theoretically, they themselves might have influenced the choice of the habitat. Even two species within a single genus (Macaca) have been found different in the integration of the vestibular and neck information (Sadeghi et al., 2009), thus the hypothesis that also humans may differ between each other in the responsivity to/reliance on/tolerance of the alteration of the various sensory modalities is conceivable.

(Data accepted by Int J Clin Exp Hypn, in press July 2010)

Study 3 - Cognitive load

Postural control is impaired in patients with lowered cognitive capacities (Manckoundia et al. 2006). As already described in Study 1, postural control and cognitive tasks compete between each other (Balasubramaniam and Wing 2002; Woollacott and Shumway-Cook 2002; Vuillerme and Vincent 2006; Fraizer and Mitra, 2008), although the former is always prioritized. A stiffening strategy (decreased CoP excursion, increased frequency of body sway) is often observed during mental activities (Vuillerme and Vincent 2006; Raymakers et al. 2005); however, the postural effects of concurrent cognitive activity depend on the characteristics of the cognitive tasks (such as spatial or non spatial) and on their difficulty (Fraizer and Mitra 2008). For instance, an easy cognitive task shifting the focus of attention away from posture control decreases the CoP excursions likely by triggering a more automatic control, while more demanding cognitive activities increase them (Olivier et al. 2007; Huxhold et al. 2006) due to the consumption of attentional resources unconsciously engaged in postural control. On the other side, the attentional cost of balance, expressed by longer reaction times to concomitant cognitive tasks, is proportional to the difficulty of the postural condition and to the individual postural expertise (Vuillerme and Nougier 2004), and is increased by sensory alteration experimentally induced (see Santarcangelo et al. 2004) or due to age and pathology (Horak and Hlavacka 2001; Shaffer and Harrison 2007; Dieterich 2007). Study 1 and, to a lower extent, Study 2 have suggested that the hypnotizability-related differences in postural control should depend on different set points for postural control in Highs and Lows, but they did not exclude a role for attention. The aim of the experiment was investigating its possible involvement in the postural responses to sensory alteration described by administration of a cognitive load.

Methods

Subjects

Participants were divided in 2 groups: 11 Highs (SHSS score,$mean \pm SE$, 10.6 ± 0.7, 6 females) and 11 Lows (SHSS score, 1.4 ± 0.4, 7 females). Height ($mean \pm SE(cm)$. Highs, 169.73 ± 2.84 ; Lows, 170.56 ± 1.25), weight ($mean \pm SE(kg)$. Highs, 63.910 ± 2.45; Lows, 65.67 ± 2.37) and foot size (shoe size, $mean \pm SE$. Highs, 40.64 ± 1.02; Lows, 40.89 ± 0.67) were similar in Highs and Lows.

Experimental procedure

The experimental procedure consisted of one session including an easy (stable support, *firm*) and a difficult (unstable support due to interposition of an 8 cm thick piece of foam between the feet and the platform) postural condition. At the beginning of the experiment, the subjects, standing on the stable support, were asked to fixate a point and to report their perception of sway (score range: min 1- max 10). All reported perceiving themselves as absolutely stable and scored their sway 1. Then they were invited to close their eyes (B, basal conditions, 1 min duration) and, finally, still keeping their eyes closed, to perform a mental computation (MC) including serial subtraction and multiplication (MC, 1 min duration). Support conditions were randomized among subjects and separated by 1 min of rest in sitting position. Basal and computation conditions were not randomized in order to avoid outlasting effects of computation. At the end, the subjects were interviewed about their perception of sway during B and MC with respect to their initial evaluation of sway, and about the effort required by mental computation (score range: min 1-max 10).

Data analysis

The analogue X-Y output from the platform was acquired by a Labview system and stored for subsequent analysis of the CoP movement standard deviation (SD), an index of the displacement of the CoP position around its mean value. In fact, absorption in cognitive tasks has been associated with smaller variability (standard deviation) of the CoP movement, suggesting an increase in the "automaticity" of postural control (Donker et al. 2007; Cavanaugh et al. 2007). The scores of the perceived sway and of the computation effort, SD, CoP Area, Velocity and LFS were analyzed through separate repeated measures ANOVAs according to the following experimen-

tal design: 2 Groups (Highs, Lows) x 2 Support conditions (*firm*, *foam*) x 2 Tasks (B, MC). Post hoc analysis was performed through paired or unpaired t test, when appropriate. Level of significance was set at $p < 0.05$.

Results

Interview

No hypnotizability effect and interaction with the task and the support condition was observed in sway perception. Both groups reported a significantly larger sway ($F(1,20) = 33.771, p < 0.0001$) during B ($5.40 \pm 0.39$) than during MC ($4.56 \pm 0.51$) as well as ($F(1,20) = 8.887, p < 0.007$) in the *foam* ($5.93 \pm 0.43$) than in the *firm* condition (3.73 ± 0.47). The effort required by mental computation was experienced as a moderate one; it was similar in Highs and Lows as well as in the *firm* (Highs, 5.50 ± 0.58; Lows, 5.77 ± 0.69) and *foam* (Highs, 5.41 ± 0.57; Lows, 5.09 ± 0.66) postural condition.

CoP movement

Standard Deviation

In the frontal plane (Tab.C.1 see Appendix C), the standard deviation (SD) of the CoP positions decreased significantly during mental computation (Task effect, $F(1,20) = 11.909, p < 0.003$). It increased significantly in the *foam* condition (Support effect, $F(1,20) = 42.909, p < 0.0001$), while no Group effect and interaction were found. Also in the sagittal plane (Tab.C.1 see Appendix C) SD increased significantly in the *foam* condition (Support effect, $F(1,20) = 29.172, p < 0.0001$) and decreased significantly during MC (Task effect, $F(1,20) = 11.455, p < 0.003$); however, the significant Support x Task interaction ($F(1,20) = 8.332, p < 0.009$) revealed that, in both groups, significant changes in SD during MC occurred only in the *foam* condition ($F(1,20) = 14.021, p < 0.001$).

Finally, the significant Task x Group interaction ($F(1,20) = 3.977, p < 0.003$) showed that the latter effect was significant only in Highs ($F(1,10) = 15.818, p < 0.003$) (Fig. 8).

Velocity

ANOVA revealed that the CoP mean velocity (Tab.C.2 see Appendix C) increased in the foam postural condition in both groups either during B or

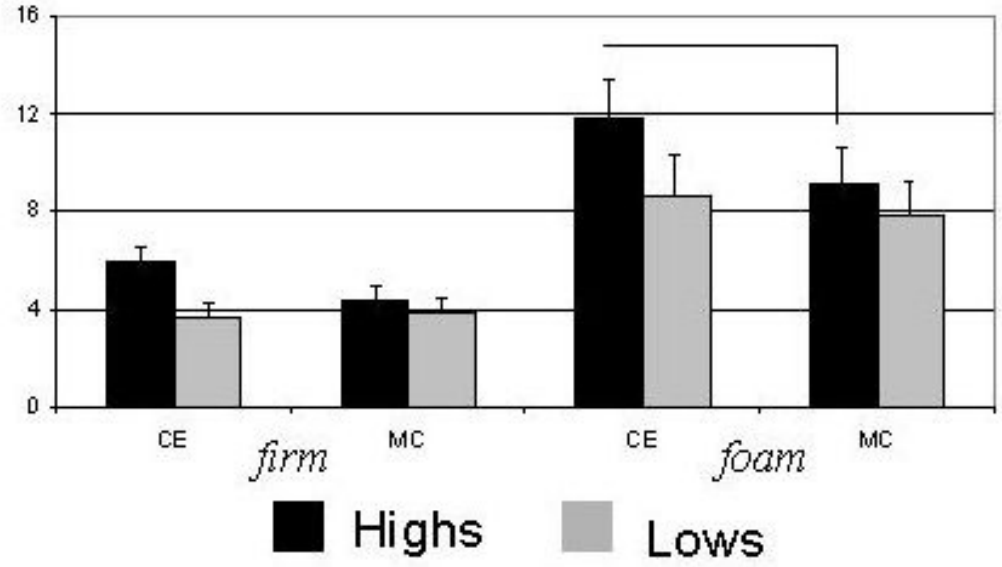

Figure 8: Standard Deviation, Task x Group interaction, CE = Closed Eyes, MC = Mental Computation, line = between condition significant difference.

MC (Support effect, $F(1,20) = 65.43, p < 0.0001$). MC did not modify the CoP mean velocity.

Area

In both groups Area (Tab. C.3 see Appendix C) was significantly larger in the *foam* than in the *firm* condition (Support effect, $F(1,20) = 19.205, p < 0.0001$) and significantly smaller during MC than during B (Task effect, $F(1,20) = 8.030, p < 0.010$). No significant interaction among Group, Support and Task was found.

LFS

A significant Support effect ($F(1,20) = 9.399, p < 0.006$) as well as significant Task x Group ($F(1,20) = 4.392, p < 0.049$) and Support x Task x Group interactions ($F(1,20) = 7.573, p < 0.012$) were found. Decomposition of the latter revealed that Highs (Fig. 9) decreased their LFS during MC in both postural conditions ($F(1,10) = 5.431, p < 0.042$), while Lows (Tab.

C.4 and Tab. C.5) increased it significantly in the *foam* condition (F(1,10) = 9.837, $p < 0.011$). In this group (Fig. 9), in the *foam* condition the LFS values during MC were higher than during B ($t(1, 10) = 2.725, p < 0.021$) and higher than those observed during MC in the *firm* condition ($t(1, 10) = 3.819, p < 0.003$).

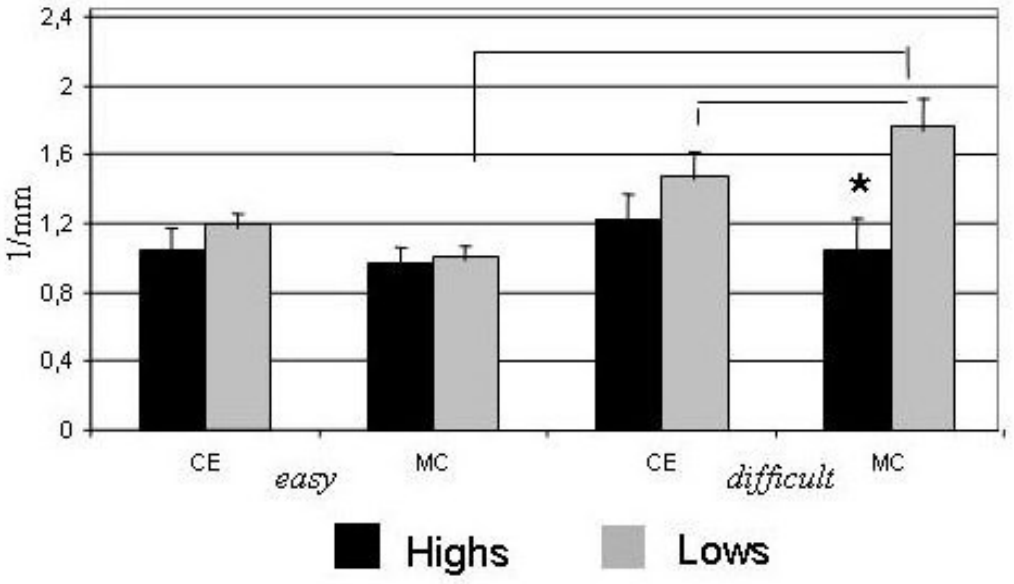

Figure 9: LFS, Support x Task x Group interaction, CE = Closed Eyes, MC = Mental Computation, line = between condition significant difference, * = between groups significant difference.

Discussion

The results showed that hypnotizability modulated the changes induced by mental computation in the variability (standard deviation) of the CoP movement that decreased only in Highs, and LFS that decreased in Highs (in both postural condition) and increased in Lows (in the *foam* postural condition). On the contrary, hypnotizability did not affect the movement complexity, area and mean velocity. Thus, the present findings do not confirm the hypothesis of a lower vulnerability of Highs to the postural effects of cognitive load, although the moderate level of effort reported by all par-

ticipants during computation might have been responsible for the few postural differences observed between Highs and Lows. Moreover, the lack of randomization of the basal and computation conditions does not allow excluding that the decrease in the variability of the CoP movement observed during computation in Highs (*foam* condition) was due to greater habituability/learning. Higher habituability, indeed, has been shown in Highs for spinal reflexes (Santarcangelo et al. 1989; 2003) and psychogalvanic responses (see Gruzelier 2006). In our subjects, the CoP area was more responsive than the CoP mean velocity to cognitive load. The decreased area during mental computation indicates a task-related stiffening strategy in both Highs and Lows and accords with other authors' findings on mental computation obtained in individuals not selected according to hypnotizability (Fraizer and Mitra 2008). The opposite LFS changes observed in Highs and Lows during mental computation in the foam postural condition support the view that different strategies for postural control operate in the two groups. However, the unstable support, instead of cognitive load, might be responsible for this behaviour, since computation did not increase the Lows' LFS in the *firm* postural condition and, in addition, the difference between the two groups in LFS was similar to that observed during visual/leg proprioceptive alteration not associated with cognitive load (Study 1). The variability of the position of the Highs' centre of pressure was also greater than that reported by other authors in subjects not selected according to hypnotizability (Donker et al. 2007). This further support the view that hypnotizability might account for a part of the variability of the general population, as occurs for other individual traits, i.e. anxiety (Davis et al. 2009). In conclusion, the present findings do not confirm the hypothesis that the Highs' postural control is less vulnerable than the Lows' one to cognitive load and indirectly indicate that the differences observed between Highs and Lows during sensory alteration (Study 1) were due to higher automaticity of the Highs' central control mechanisms, instead of greater availability of attentional resources and/or better ability to allocate them. The hypothesis of a higher independence of the context in the Highs' behaviour is supported also by findings obtained during blindfolded locomotion that is scarcely influenced by changes in sensory information, i.e due to head rotation (Menzocchi et al., 2009).

(data published in Exp Brain Res, 194, 323-328, 2009)

Part III

Hypnotizability, imagery and posture

Imagery - the ability of seeing with the mind's eye, hearing with the mind's ear ..." (Kosslyn et al., 2001) - has been largely investigated within the theoretical frame of the relationship between bottom-up and top-down processes. Partially similar cortical activations have been observed during perception and imagery for all sensory modalities (see Carli et al, 2007), although the occurrence of visual imagery in subjects blind from birth and in patients with lesions of visual sensory areas (Moro et al., 2008) suggests that imagery and perception may not share the same neural pattern (Mechelli et al., 2008; Bartolomeo, 2008). Moreover, motor imagery specifically enhances or reduces the corticospinal excitability of the motoneurons involved in imagined voluntary movements (Jeannerod, 2001; Fourkas et al., 2006; Li et al, 2007; Bakker et al., 2008; Liepert and Neveling, 2009) and imagery of head rotation induces vestibulo-ocular reflexes (Rodionov et al., 2004). Hypnotic suggestions are requests of specific mental imagery. Indeed, high hypnotizability has been associated with peculiar imagery abilities, i.e. vividness (Crawford, 1982; Lynn and Rhue, 1986; Crawford and Allen, 1996) and absorption (Tellegen and Atkinson, 1974). Poor imagers have never been found among highly hypnotizable people (Highs), although good imagers can be found among low hypnotizable persons (Lows) (Glisky et al., 1995; Kogon et al., 1998). In Highs, suggestions for altered perception/movement induce congruent physiological changes and subjective experience associated with perception of involuntariness/effortlessness also in the normal non hypnotic state. For instance, suggestions for analgesia and arm heaviness decrease the activity of somatosensory areas (Derbyshire et al., 2009) and induce arm lowering (Santarcangelo et al., 2005), respectively. In addition, it has been hypothesised that Highs can "translate" sensory imagery into perception and behave accordingly to a real stimulation. Indeed, during suggestions of falling backward not explicitly describing the expected response ("... the carpet under your feet is being pulled forward...") Highs fall backward and report involuntariness and unpredictability of their movement (Carli et al., 2006).

Study 4 - Imagery of anaesthesia and of head rotation

Aim of the present experiment was to support the hypothesis of an equivalence between imagery and perception in Highs based on top down activation of appropriate sensori-motor circuits. Imagery of anaesthesia - a classical obstructive instruction aimed at suppressing/reducing stimulus perception - and of tonic head rotation - supposed to create a new sensory context- were chosen as imagery tasks. The vestibulospinal (VS) reflex was used as test stimulus because it is scarcely affected by volition (Reynolds et al., 2009) and expectation (Guerraz and Day, 2005) and is modulated by changes in head orientation, as labyrinth-driven body displacement occurs mainly in the frontal plane when the head is directed forward and in the sagittal plane when the head is rotated with respect to the trunk (Lund and Broberg, 1983). Thus, in subjects having their head directed forward, effective imagery of anaesthesia should reduce the amplitude of body sway in the frontal plane and effective imagery of head rotation should shift the VS reflex main direction of sway from the frontal to the sagittal plane.

Methods

Subjects

13 Highs ($score > \frac{9}{12}$, 9 females) and 13 Lows ($score < \frac{2}{12}$, 7 females) were enrolled in the study. They completed the Tellegen Absorption Scale (TAS) (Tellegen and Atkinson, 1974) for assessment of their abilities to be involved in their own mental images. Height ($mean \pm SD$. Highs, 171.54 ± 9.22; Lows, 169.23 ± 11.07 cm), weight (Highs, 67.69 ± 12.47; Lows, 62.62 ± 11.63 Kg) and foot size (Italian shoes measure. Highs, 40.77 ± 3.03; Lows, 40.23 ± 3.17) were similar in Highs and Lows.

Experimental procedure

The experimental session began with a 20 sec fixation of a point positioned 120 cm away from the subject, at eyes level, followed by eyes closure. With eyes closed, the participants underwent two different series of experimental conditions. One consisted of monitoring the centre of pressure (CoP) movement while the subjects' face was directed forward both in the absence of tasks (HF) and during guided imagery of anaesthesia (HF_{AN}); the other series included CoP monitoring during real tonic head rotation (HRr) toward the right side and during guided imagery of the same head rotation (HRi). The order of the two series, separated by a 2 min rest in sitting position, was randomized among the subjects of the Highs' and Lows' groups. During all conditions (HF, HF_{AN}, HRr, HRi), lasting 2 min each, subjects received galvanic vestibular stimulation (GVS). During HRi, the position of the chin with respect to the shoulders was visually monitored by one of the experimenters. At the end of HF_{AN}, participants were asked to score the perceived intensity of stimulation as compared to that perceived during HF ($score = 100$); at the end of HRi, they were asked to evaluate the vividness of their imagery of head rotation (score 1-10). For both conditions the participants were asked to say whether their imagery was subjectively more vivid at the beginning (first minute) or at the end (second minute) of the stimulation period. They were also asked about the modality (visual and/or proprioceptive) mainly used to imagine the head rotation. Guided imagery of anaesthesia consisted of instructions focused on the absence of stimulus perception and of any stimulus related distress ("Now you are not perceiving any electrical stimulation, as if your head has been anaesthetized... the whole situation is relaxing...you cannot perceive any electrical stimulation any longer..."). Guided imagery of tonic head rotation consisted of instructions for imagery of tonic head rotation focused on both the visual perception of the chin position with respect to the right shoulder and the proprioceptive perception of tension in the neck muscles ("Now your head is rotated as it was before, ...you can feel the tension in your neck muscles and see your chin facing your right shoulder...the same situation you experienced before...") GVS consisted of electrical train pulses (repetition rate 0.25 Hz) of 300 msec (1ms pulse duration, interpulse interval 40 μ sec) delivered between the two mastoid bones (cathode on the right side) by an isolated, constant-current stimulator (Digitimer model DS7A) driven by a master generator (Ortec, model 4650). In order to elicit unpredictable stimuli, the master generator was triggered at a computer-controlled, pseudo-random frequency (range: 5-8 sec). The current intensity delivered was checked at the end of the stimulation by measuring the voltage drop induced by the current across a $1k\Omega$ resistor. In each subject, the stimulus

intensity used was 1.2 x the lower stimulus intensity inducing the perception of definite body sway ($mean \pm SD.\ 9.2 \pm 1.6mA$). The GVS intensity administered was similar in Highs and Lows

Data recording and analysis

Data were acquired and analyzed through a Lab-view software prepared ad hoc (sampling rate: 100 Hz) and used to calculate the peak latency and amplitude of the stimulus-locked postural sway (vestibular spinal (VS) reflex) in the frontal and sagittal plane. These variables were evaluated on averaged traces (20 sweeps, each of them including a pre-stimulus period of 0.5 sec and a post-stimulus period of 1 sec (Fig.10) of the CoP coordinates (X and Y axis), each condition was divided in 2 parts lasting 1 min. The vestibular reflex elicited by bipolar labyrinthine stimulation consists of an earlier CoP displacement beginning at about 170 msec, directed toward the cathode and of a later one directed toward the anode. In order to minimize pre stimulus movement bias, the regression line of the first 600 msec was subtracted from the averaged traces.

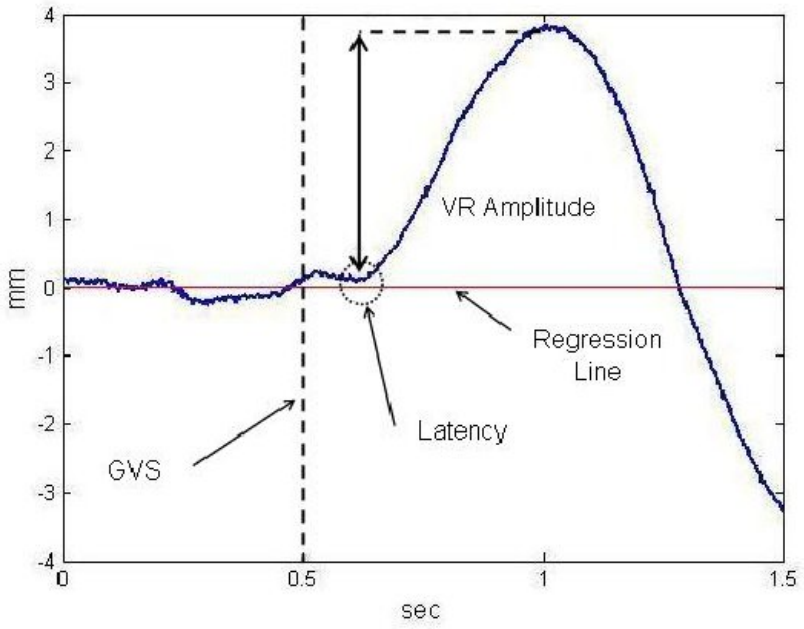

Figure 10: Vestibulo Spinal Reflex. The dashed line indicates the beginning of the electric stimulation

The analysis of the imagery effects was focused on the earlier compo-

nent which is due to labyrinthine-elicited muscle forces displacing the body toward the anode (Hlavacka and Horak, 2006) and, at least for the initial part, in less affected than the second one by extralabyrinthine inputs elicited by body displacement. The reflex response peak amplitude corresponded to the difference between the coordinates of the highest and lowest position assumed by the CoP during this earliest reflex response. The contribution of cutaneous stimulation to the observed CoP responses can be excluded, as the displacement of the electrodes from the mastoid process to the neck (at the level of the fifth cervical vertebra) failed to produce changes in the CoP position. Moreover, increasing the interstimulus interval of the train pulses from 40 μsec to 3-6 msec abolished the CoP responses, but not the pricking ear sensation elicited by the stimulus; this indicates that stimulation of the cutaneous afferents of the mastoid region is not responsible for postural responses. Group differences in the scores of TAS as well as of the perceived stimulus intensity and of the vividness of the imagery of head rotation were analyzed through univariate ANOVAs. Detrended VS reflexes traces (N=10) of the first or second recording minute were selected for analysis according to the subjectively experienced time course of imagery. VS reflex peak amplitudes and latencies were analyzed through repeated measures ANOVAs with hypnotizability (Group) as between subjects factor. Within subjects comparisons concerned HF_{AN} vs HF and HRi vs HRr on the whole Highs and Lows groups as well as only on good imagers from the two groups (subjects reporting a stimulus intensity $< 65\%$ HF during HF_{AN} and imagery vividness $>$ 6 during HRi). The Greenhouse-Geisser ϵ correction for non-sphericity was applied when appropriate. Level of significance was set at $p < 0.05$.

Results

In absence of any suggestion, the comparison between HRr and HF showed larger amplitudes in the frontal plane when the head was directed forward (HF: $(F(1, 24) = 5.562, p < 0.027)$ and in the sagittal plane when it was rotated (HRr: $(F(1, 24) = 11.377, p < 0.003)$. The Tellegen Absorption Scale (Tellegen and Atkinson, 1974) showed similar ability of involvement in their own mental images in Highs and Lows. Guided imagery induced changes in the amplitude, but not in the peak latency of the first VS reflex component during both imagery tasks.

Imagery of anaesthesia

During HF_{AN} Highs perceived a significantly lower stimulus intensity than Lows ($F(1,25) = 7.455, p < 0.012$) (Fig. 11 A). In the frontal plane both groups showed a reduced VS amplitude (Fig. 11 B) with respect to the HF condition ($F(1,24) = 15.996, p < 0.001$). Yet, decomposition of the quasi significant Condition x Group interaction ($F(1,24) = 3.838, p = 0.062$) indicated that imagery decreased the VS reflex amplitude only in Highs ($F(1,12) = 17.309$, $p < 0.001$). In the sagittal plane, the VS peak amplitude did not show any significant difference between HF and HF_{AN} in both groups (Fig. 11 C). Since also some Lows reduced their stimulus perception during HF_{AN}, "good imagers " were selected in each group. In the comparison between these subgroups (10 Highs and 5 Lows perceiving a stimulus intensity < 65 of HF), no hypnotizability-related difference was observed for TAS scores, perceived stimulus intensity (Fig. 11 D) and VS reflex amplitude in the frontal plane (Fig. 11 E) which was similarly reduced in both groups ($F(1,13) = 10.555, p < 0.006$). In the sagittal plane, the VS reflex peak amplitude did not show any significant difference between HF and HF_{AN} in both groups (Fig. 11 F).

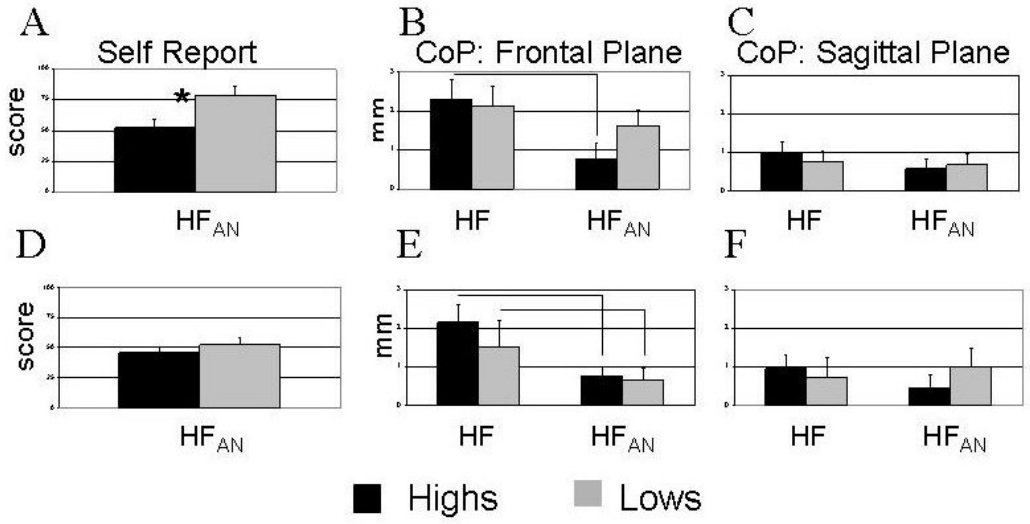

Figure 11: A-C All subjects, D-F Good imagers, A,D self report, B,E CoP Frontal Plane, C, F CoP Sagittal plane, HF = Head Forward, HF_{AN} = guided imagery of anaesthesia, line = between condition significant difference, * = between groups significant difference.

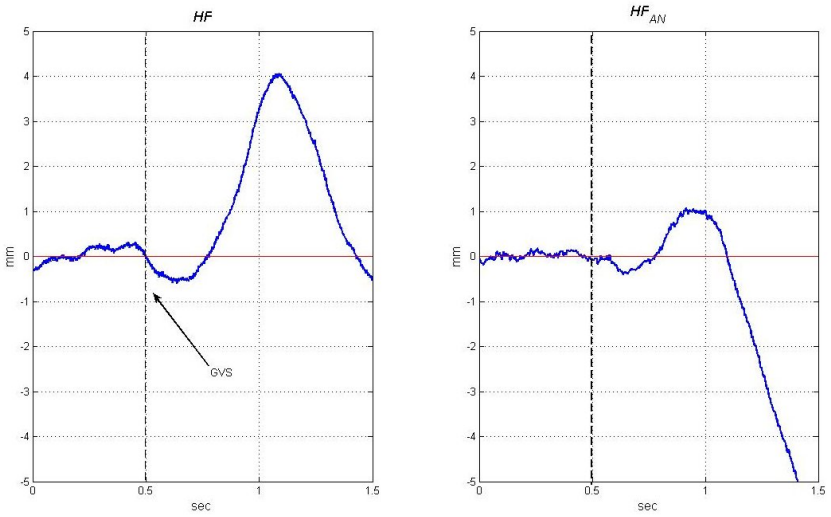

Figure 12: Good Imager representative subject, Frontal plane, HF=Head Forward, HF_{AN} = guided imagery of anaesthesia.

Imagery of head rotation

During HRi Highs perceived a quasi significantly higher vividness of imagery than Lows ($F(1,25) = 3.999, p = 0.057$) (Fig. 13 A). Ten Highs and 5 Lows reported to have used the proprioceptive modality of imagery, while 3 Highs and 8 Lows chose the visual one. In the sagittal plane, VS reflex peak amplitudes during HRi and HRr were not significantly different in Highs (Fig. 13 B), while Lows exhibited lower VS reflex amplitudes during HRi ($F(1,12) = 11.923, p < 0.005$). In the frontal plane (Fig. 13 C), the VS reflex amplitude increased ($F(1,24) = 4.285, p < 0.049$) in both groups during imagery. Among good imagers (12 Highs and 7 Lows scoring imagery vividness $>$ 6 out of 10), no significant difference between Highs and Lows was observed in TAS scores and vividness of imagery (Fig. 13 D). However, 9 Highs and only 2 Lows reported to have used the proprioceptive modality of imagery. Similarly to the entire groups, in the sagittal plane, during HRi, Highs exhibited VS reflex peak amplitudes not significantly different from HRr, while, in the same condition, Lows showed VS reflex amplitudes significantly lower than during HRr ($F(1,6) = 8.150, p < 0.029$) (Fig.13 E). Instead, both subgroups were able to avoid increases in the frontal VS reflex component (incongruent with the suggestion) (Fig. 13 F) observed in the total samples of Highs and Lows during HRi.

In summary, both Highs and Lows reporting high vividness of imagery

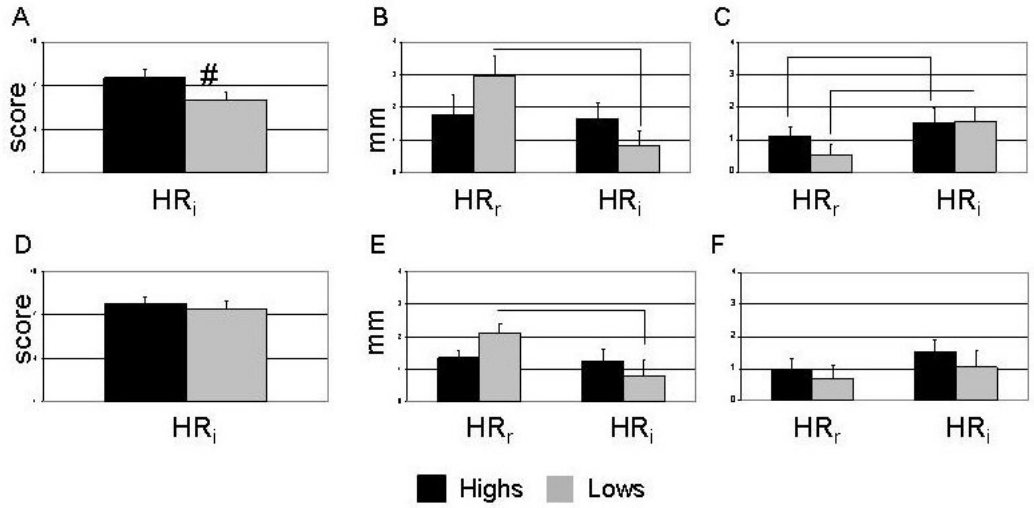

Figure 13: A-C All subjects, D-F Good imagers, A,D self report, B,E CoP Sagittal Plane, C, F CoP Frontal plane, HRr = Head Rotated, HRi = guided imagery of head rotated, line = between condition significant difference,♯= between groups *quasi* significant difference.

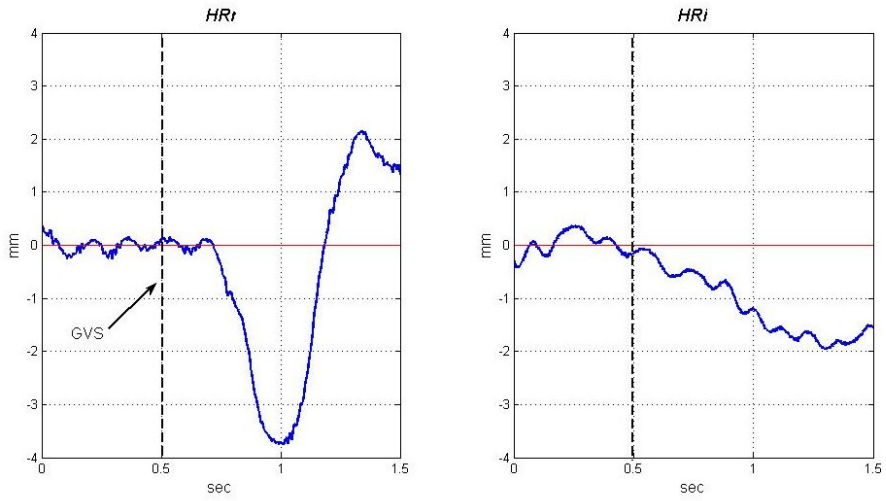

Figure 14: Poor Imager representative subject, Sagittal plane HRr = Head Rotated, HRi = guided imagery of head rotated

experienced anaesthesia and reduced their VS reflex amplitude accordingly.

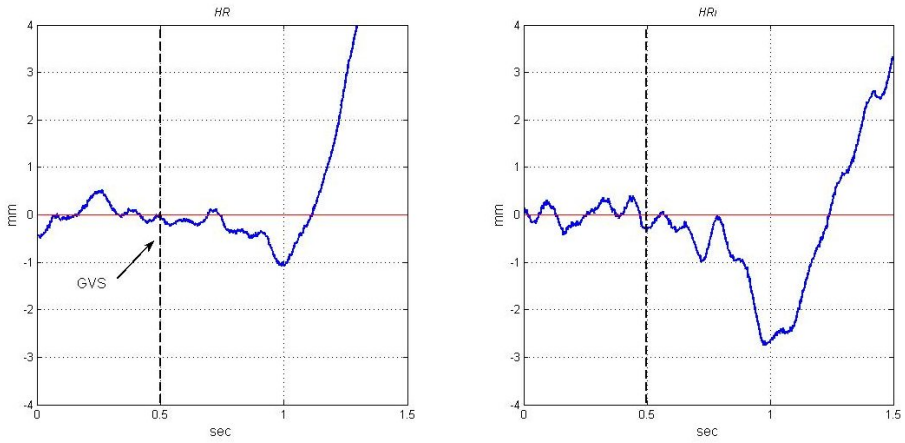

Figure 15: Good Imager representative subject, Sagittal plane HRr = Head Rotated, HRi = guided imagery of head rotated

At variance, only Highs (who chose the proprioceptive modality of imagery preferentially) changed the preferential plane of body sway according to their imagery of head rotation in spite of vividness of imagery and absorption scores similar to Lows.

Discussion

The present results indicate a cognitive modulation of the vestibulo-spinal reflex, as imagery of altered perception obtained through obstructive (anaesthesia) and "constructive" suggestions (head rotation) affects its amplitude. Earlier reports of cognitive modulation of the VS reflex concern only a slight amplitude reduction elicited by the instruction to stand still (Reynolds et al., 2009) and stimulus expectation (Guerraz and Day, 2005). On the contrary, a cognitive modulation of the vestibulo-ocular reflex by hypnotic suggestions (Ashan et al., 1962) and by expectation/knowledge of the stimulus characteristics had already been observed (Ramat et al., 2005). The physiological basis of the VS reflex in humans are not definitely assessed, but the latency of the muscle responses associated with the observed body sway is compatible with an extensive central processing involving cortical regions receiving vestibular volleys (prefrontal and frontal lobe, ipsilateral temporoparietal cortex, anterior portion of the supplementary motor area, contralateral parietal cortex) (de Waele et al, 2001). Vestibulo spinal reflexes could be modulated in these regions or at the level of vestibular nuclei, which receive afferents from the cerebral cortex (Wilson et al, 1999). On the other hand, the activity of areas

receiving from and projecting to vestibular nuclei as well as of the vestibular complex itself is influenced by projections from the locus coeruleus (LC) (Waterhouse et al., 1983), which receives vestibular volleys (Pompeiano et al, 1991), regulates the gain of vestibular reflexes (d'Ascanio et al., 1985) and shows an alertness/attention dependent modulation (Berridge and Waterhouse, 2003; Nieuwenhuis et al., 2005). At lower levels, also less specific mechanisms such as a general decrease/increase of the motoneuronal excitability (Fig. 16) could be involved, as occurs during relaxation (Taniguchi et al., 2008),

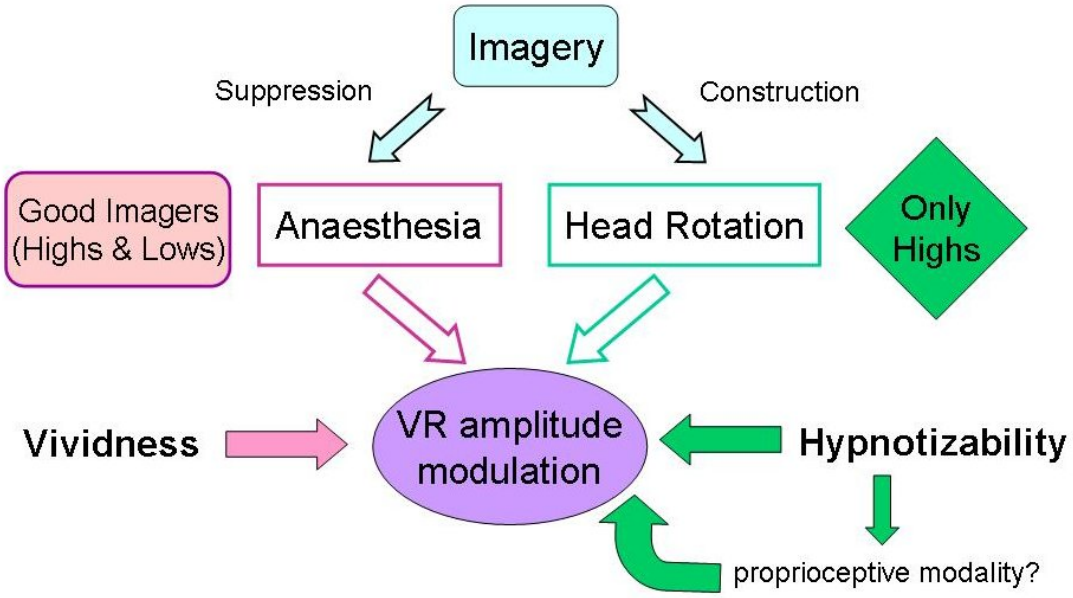

Figure 16: Modulation of VS Reflex by Imagery

movement imagery (Jeannerod, 2001; Fourkas et al., 2006; Li et al, 2007; Bakker et al., 2008; Liepert and Neveling, 2009) and observation (Léonard and Tremblay, 2007; Liepert J, Neveling 2009). However, the main role in the present results is likely to be exerted by the cerebellum, which is responsible for both VS reflex gain modulation (Manzoni et al., 1998) and for the shift from a frontal to a sagittal main VS reflex component when the head is

rotated on the trunk (Shaikh et al., 2005; Manzoni, 2005). Indeed, cerebellar patients are unable to change the plane of maximum sway after rotation of their head (Kammermeier et al., 2009). Our results confirm that the relation between imagery and hypnotizability is complex (Fig. 16). In fact, good imagers have been found either among Highs or among Lows, although more numerous among Highs. They had the same ability of involvement in their own mental images and, when experienced the same vividness of imagery, were able to translate a reduced stimulus perception into a reduced vestibular reflex amplitude during imagery of anaesthesia. On the contrary, only Highs could "create" a sensory context similar to real head rotation through imagery, may be due to cognitive abilities allowing them to select appropriate top-down processes activating specific sensory areas and/or, ultimately, modifying the activity of cerebellar structures. Thus, the obstructive suggestion of anaesthesia appears to be qualitatively different –somehow easier- with respect to the "constructive" imagery of head rotation. Theoretically, the difference between Highs and Lows in the efficacy of the imagery of head rotation might be accounted for by more efficient corollary copies of motor commands and by a consequent greater cover motor activity in Highs, which could be responsible for differences in the proprioceptive state and, thus, in the change in the preferential sway direction. However, increased cover activity alone cannot be responsible for the observed results, as no change in head position was observed during imagery of head rotation. Moreover, it has been shown that the changes in VS reflex induced by head rotation depends much more on the proprioceptive sensory signals than on the copy of the motor command to neck muscles (Fransson et al., 2000). A possible basis for the hypnotizability related effects of the imagery of head rotation might be the sensory modality of imagery chosen, as most of the Highs and only few Lows chose the proprioceptive one. The role of the two modalities in the construction of the body schema is a function of the behavioural context (Shenton et al., 2004; Stinear et al., 2006). Indeed, an "egocentric", intrinsic coordinates system seems to be required in subjects standing still, while an extrinsic coordinates system is required by movements in space (see Shenton et al., 2004). In addition, stronger activity in the anterior and posterior parts of the SMA during kinestetic than during visual imagery has been found during imagery of finger movements (Guillot et al., 2009). In conclusion, in the sensori-motor domain imagery can simulate perception and the cognitive trait of hypnotizability is relevant in this process. In fact, an equivalence between sensory imagery and perception is more likely and effective in highly hypnotizable persons.

Data presented at the Satellite Pre-Conference (Hypnotizability as a component of physiological variability) of the 60° Congress of the Italian Society of Physiology, September 15-17, Siena, and at the Satellite Pre-Conference (Basic mechanisms underlying balance control under static and dynamic conditions) of the International Society for Posture and Gait Research,, June 19-20 2009 Pavia,

Study 5 - Imagery of pain

A connection between postural control and hypnotizability concerns the well-known modulation of body sway by affective traits/conditions, i.e. anxiety and fear of falling (Adkin et al. 2002; Carpenter et al. 2006; Laufer et al., 2006; Hauck et al. 2007; Redfern et al. 2007) and the different emotional behaviour shown by Highs and Lows during stressful conditions. Indeed, non-hypnotized Highs can buffer the autonomic correlates of unpleasant guided imagery (Santarcangelo and Sebastiani 2004) and the endothelial dysfunction associated with mental computation (Jambrik et al. 2004) and experimental pain (Jambrik et al. 2005; Balocchi et al. 2005). Theoretically, a similar ability might modulate the changes in body sway associated with emotion and stress induced by pain imagery. However, the findings of Study 4 indicate that the bodily translation of the sensory content of some imagery tasks may be "easier" than other ones. In fact, imagery of anesthesia is effective in good imagers of high and low hypnotizability, while imagery of head rotation is effective only in Highs, in spite of imagery vividness and trait absorption similar to Lows. Pain imagery seems to be particularly difficult. This may be due to the several dimensions of the pain experience and to the wide distribution of the "pain matrix" areas to activate through imagery (Derbyshire et al., 2004). Indeed, some authors reported that, at variance with hypnotic suggestions, non hypnotic guided imagery of pain is able to induce pain imagery, but not pain perception in healthy Highs (Derbyshire et al., 2004) and others showed that imagery is not responsible for the effects of hypnotic suggestions for analgesia (Hargadon et al., 1995). On the other hand, previous studies from our group have shown that awake Highs can experience pain during pain imagery, although the perceived pain intensity was lower than during the corresponding real stimulation. In addition, cardiovascular correlates of pain imagery are slightly, but significantly more pronounced in Highs (Paoletti et al., 2009). Aim of the present experiment was to assess whether pain imagery produces appropriate postural modifications, as observed for other sensory modalities (Study 4 , this Part). In particular, during normal bipedal stance the experience of segmental pain (foot/leg pain, LP) is ex-

pected to displace the body centre of pressure (CoP) toward the opposite side, while imagery of neutral tactile stimulation (NS) of the same leg/foot as well as throat (central, visceral) pain (TP) should not elicit asymmetrical body displacement. NS and TP are expected to modulate the CoP movement like a low and a high attentional/threatening task, respectively (Fraizer and Mitra , 2008; Huxhold et al., 2006; Olivier et al., 2007)

Methods

Subjects

12 Highs ($score > 9/12$, 9 females) and 10 Lows ($score < 3/12$, 8 females) were enrolled in the study. Height ($mean \pm SD$. Highs, 169.40 ± 7.52; Lows, 167.03 ± 9.12 cm), weight (Highs, 65.50 ± 10.32; Lows, 62.33 ± 10.49 Kg) and foot size (Highs, 39.35 ± 3.03; Lows, 40.01 ± 3.22, italian shoes measure) were similar in Highs and Lows.

Experimental procedure

Before the experimental session, subjects completed the Italian version of the State-Trait Anxiety Inventory (STAI- Y) (Pedrabissi and Santinello,1989) for the assessment of their present anxiety level. At the beginning of the experiment, subjects were asked to fixate for 20 sec a point positioned 120 cm away from them, at eyes level, and to report their perception of body sway (score range: min 1- max 10), and then to close their eyes. All of them reported perceiving themselves as absolutely stable and scored their sway 1. The recording session was divided in three Parts (for leg pain imagery, throat pain imagery and neutral leg stimulation imagery) separated by 1 minute of rest during which subjects were allowed to seat. Each Part consisted of 2 Conditions lasting two minutes each: a basal condition (Basal) without instructions and a task of guided imagery (of Leg Pain, LP; Throat Pain, TP; leg Neutral Stimulation, NS). The guided imagery of LP included the description of an unpleasant setting ("...you are at the Emergency Department... the surgeon is taking out some pebbles from your left calf, he is using tweezers, he cannot avoid tearing away small pieces of flesh... unfortunately there is no anaesthetic..."). The TP imagery was described, at first, as a discomfort ("...you now feel your throat pickling...") , then growing to a painful condition ("... you feel a sharp pain in your throat... you can hardly speak, ...it feels like having splinters down your throat..."). During NS the subject was asked to imagine a pleasant tactile sensation on the left leg ("...it is a nice

feeling... you have never experienced wearing such a comfortable fabric... it feels like soft silk or light velvet ..."). At the end of every Part, subjects were asked to evaluate their perception of body sway, the vividness of the imagery, their absorption in the imagery task performed, the effort required and, for leg and throat pain imagery, their perception of pain intensity. The range of the scores of all scales was 1(min)- 10 (max).

Statistical analysis

Multivariate ANOVA was used for the analysis of self reports. Repeated measures ANOVA was used for each postural variable (Xmean, Ymean, area, velocity) according to a 2 Groups (Highs Lows) x 3 Parts (LP, TP, NS) x 2 Conditions (basal, imagery task) design. Significance was set at $p<0.05$. Due to the large number of factors, significant contrasts were considered also in the absence of significant general effects.

Results

Psychological questionnaires

State Anxiety was similar in Highs and Lows (STAI scores, $mean \pm SD$. Highs, 46.10 ± 3.81; Lows, 48.00 ± 3.32).

Interview

All subjects had experienced severe throat pain during their life; approximately the same percentage of Highs (7 subjects out of 12) and Lows (5 out of 10) had not experienced wounds similar to those described by the script used for the task of guided imagery of leg pain. As shown in Fig. 17 A-C, subjects of both groups reported similar vividness, absorption and effort for LP, TP and NS. Highs showed significantly higher scores than Lows at vividness (Fig. 17 A, C); of all imagery tasks ($F(1,19) = 10.793, p < 0.004$; TP,$F = 21.587, p < 0.0001$; NS, $F = 7.679, p < 0.013$); in addition, they perceived pain intensity(Fig. 17 D) almost double than Lows during both LP ($F = 13.704, p < 0.002$) and TP ($F = 29.345, p < 0.0001$). Body sway perception (Fig. 18)was higher in Highs during LP ($F = 8.398, p < 0.010$) and NS ($F = 6.104, p < 0.024$).

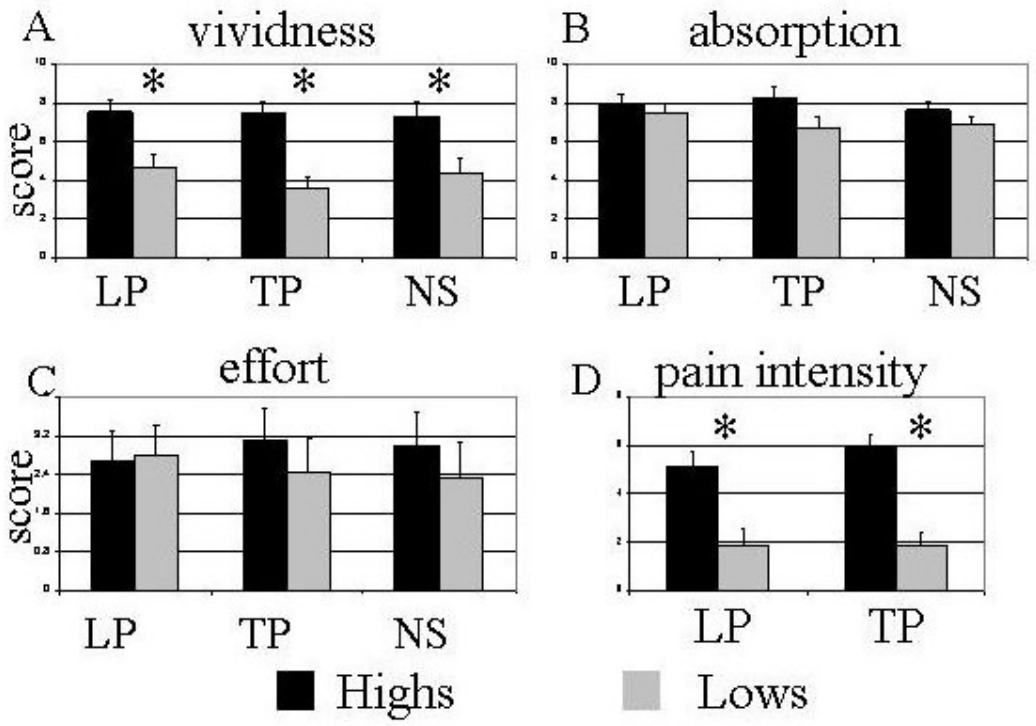

Figure 17: Interview, A vividness, B absorption, C effort, D pain intensity. LP Leg Pain, TP Throat Pain, NS leg Neutral Stimulation, * = between groups significant difference.

Postural variables

No significant difference was found among the basal conditions of the three Parts for all variables(Tab. 3).

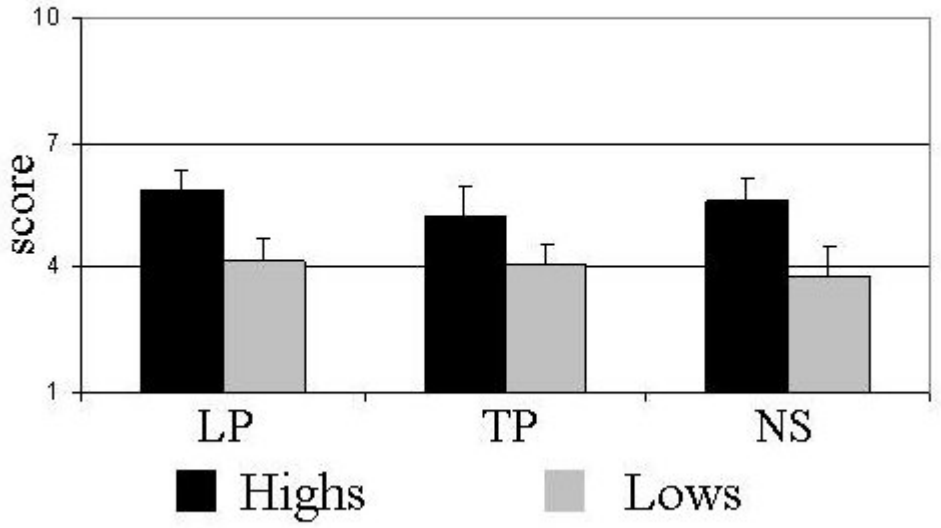

Figure 18: Interview, Body Sway Perception. LP Leg Pain, TP Throat Pain, NS leg Neutral Stimulation.

As expected, Xmean, Area and Velocity increased significantly during LP in Highs, who did experience foot/leg pain , and did not show any change in Lows, who did not feel pain (Tab. 3, Fig. 21 A, C, D). In addition, during LP Xmean and Area were significantly larger in Highs than in Lows (Fig. 19, 20).

Ymean increased during all tasks in both groups (Fig. 3 B). Good imagers (subjects exhibiting vividness of imagery higher than 5) of both groups could not be contrasted, as only 1 good imager was found among Lows. In spite of the vividness, absorption and effort similar to LP and of a perceived pain intensity in Highs double than in Lows, TP did not produce any significant postural change in both groups. No change was observed during NS (Tab. 3, 4; Fig. 21 A-D). However, in Highs Area tended to a decrease during TP and to an increase during NS, although not significantly, as expected during high and low threatening cognitive tasks, respectively (Fraizer and Mitra 2008; Olivier et al. 2007; Huxhold et al. 2006).

group	**Highs**		**Lows**		**Highs**		**Lows**	
variable	**Xmean** (mm)				**Ymean** (mm)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Basal	11.86	6.45	6.82	10.20	-38.26	19.21	-31.18	8.97
TP	14.03	5.91	5.61	7.83	-40.80	17.63	-33.67	11.03
Basal	12.53	6.82	5.69	4.65	-34.83	18.98	-28.62	14.07
NS	11.74	8.27	7.76	8.38	-37.62	15.75	-34.48	13.96
Basal	11.76	5.82	7.73	4.59	-32.67	21.31	-33.12	14.41
LP	19.20	8.73	6.62	6.31	-37.35	18.58	-30.15	11.79
	area (mm^2)				**velocity** (mm/sec)			
Basal	464.83	428.73	189.40	140.64	10.80	5.47	8.42	3.73
TP	342.17	294.96	183.90	180.83	10.78	5.88	8.59	5.30
Basal	255.00	169.57	192.50	123.64	8.73	3.34	8.81	3.02
NS	422.67	398.01	161.70	110.93	10.82	5.97	7.71	3.26
Basal	351.50	234.08	233.10	186.74	9.45	4.35	9.44	4.54
LP	678.08	490.43	269.70	302.95	12.73	6.99	8.42	2.52

Table 3: Postural Variables, TP Throat Pain, LP Leg Pain, NS leg Neutral Stimulation

Ymean	cond	F(1,20)=6.513, p<0.019		
Xmean	group	F(1,20)=7.650, p<0.012	**Highs > Lows**	
	part x group	F(1,20)=6.337, p<0.020		
	part x cond x group	F(2,40)=6.387, p<0.005	**Highs** B<LP	t(1,11)=3.685 p<0.004
area	group	F(1,20)=5.024, p<0.037	**Highs**	
	part x cond	F(2,40)=4.810, p<0.015	B<LP	t(1,11)=2.961 p<0.013
	part x cond x group	F(2,40)=3.629 p<0.039	**Lows: ns**	
velocity	cond x group	F(1,20)=5.809, p<0.026		
	part x cond x group	F(2,40)=5.011 p<0.020	**Highs**	
			part x cond	F(2,22)=6.713, p<0.010
			B < LP	t(1,11)=2.646, p<0.023
			Lows: ns	

Table 4: Postural Variables Variations

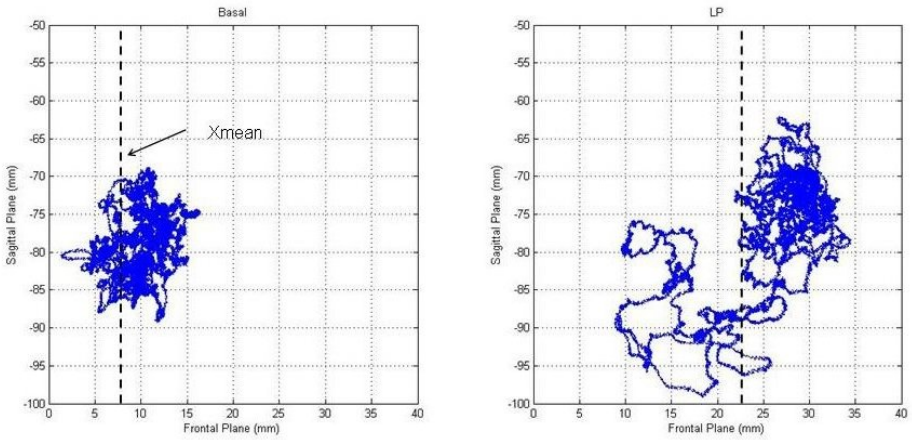

Figure 19: Centre of Pressure path, LP = Leg Pain, Highly hypnotizable representative subject, the dashed line representing Xmean shifts right from Basal to Leg Pain.

Discussion

In line with previous studies from our group (Paoletti et al., 2009), the results indicate that perception of pain can be induced by guided imagery also in not hypnotized healthy subjects. High hypnotizability is necessary for perceiving imagined pain and this effect might be mediated by vividness, which was scored higher by Highs. Highs reported high vividness and pain intensity for both segmental and central, visceral pain, but only the perception of segmental pain induced significant postural changes. Although the contribution of a voluntary component affecting the motoneurones excitability cannot be stringently excluded, the guided imagery of unilateral segmental pain seems to have modulated the activity of the neural circuits responsible for leg nociceptive reflexes and, thus, for the CoP displacement toward the right side, as occurs for vestibulo-spinal reflexes during imagined anaesthesia and head rotation. The lateral body displacement is not due to attention to the left

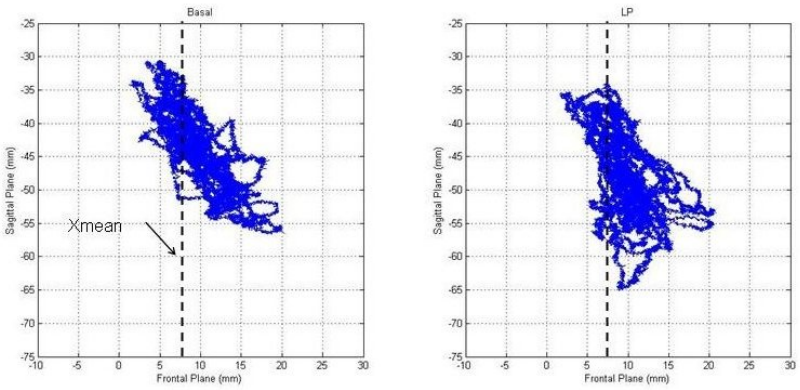

Figure 20: Centre of Pressure path, LP = Leg Pain, Low hypnotizable representative subject, the dashed line representing the Xmean value, remains constant from Basal to Leg Pain condition

leg, as no displacement was observed during imagery of tactile, non painful leg stimulation and during imagery of throat pain which is a symmetrical stimulation not involved in postural control other than for its threatening (attentional) content. The higher pain intensity perceived by Highs might depend on a possible greater ability to activate the various components of the pain matrix (Derbyshire et al., 2004). In this respect, a limitation of the study is the lack of evaluation of the emotional dimension of the experienced pain. The larger body sway perceived by Highs with respect to Lows during leg pain is likely due to their "realistic" perception of sensory alteration, while the higher perception observed during neutral stimulation but not during throat pain perception could be accounted for by the higher cognitive engagement The ability of Highs to perceive pain during pain imagery and develop neural activation appropriate to the specific pain experienced may play a role in the persistence of abdominal muscle activation observed in the asymptomatic weeks/months between two low back pain episodes (Hodges

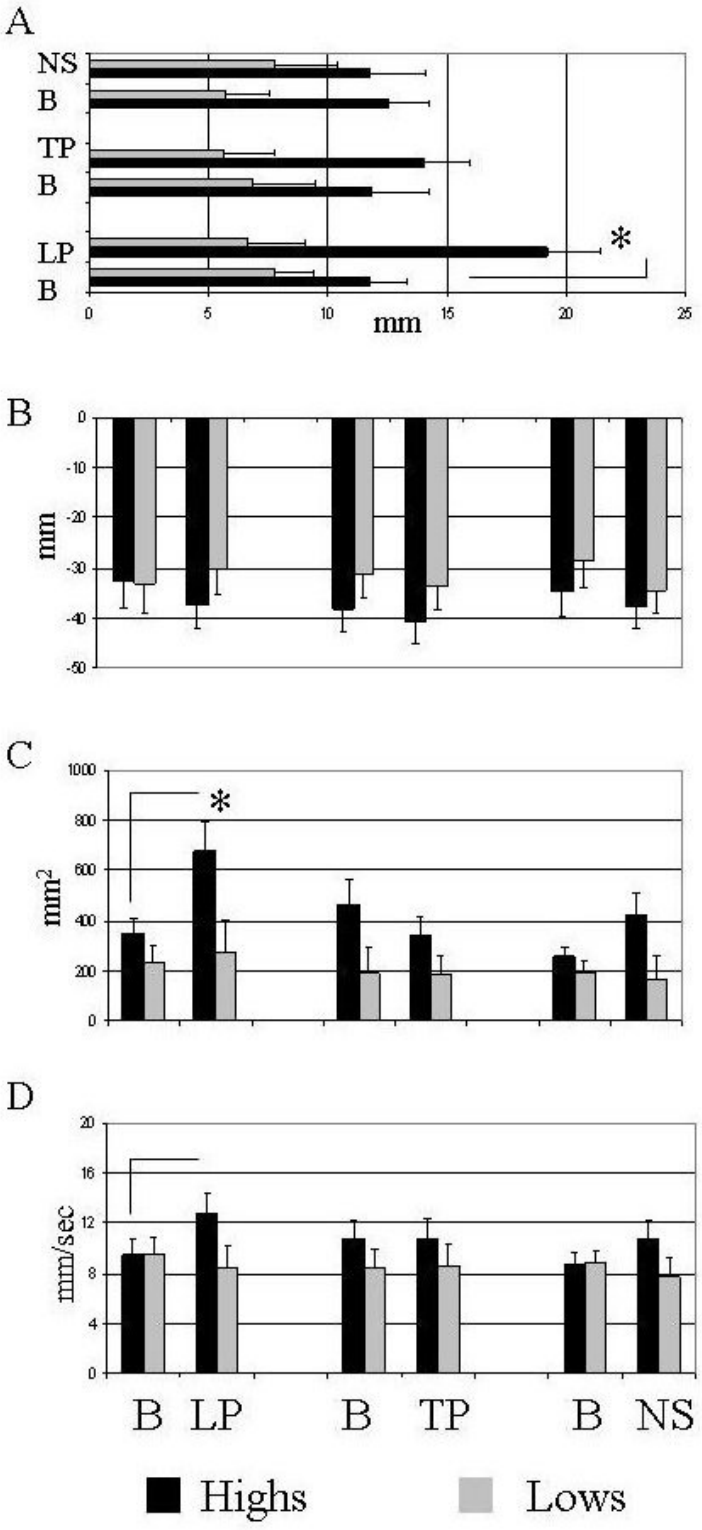

Figure 21: Postural Variables, A Xmean, B Ymean, C Area, D Velocity, B Basal, LP Leg Pain, TP Throat Pain, NS leg Neutral Stimulation, line = between condition significant difference, * = between groups significant difference.

and Richardson, 1996). This would be in line with the role suggested for imagery in the development of chronic pain (Crawford et al., 1998), phobias and post-traumatic stress disorder (Wickramasekera 1993, 1996). It has been suggested that the higher prevalence of the latter diseases among Highs might depend on their greater ability to re-experience phobic objects and traumatic events through their body that is associated with activation of the autonomic system (Wickramasekera, 1993; 1996). However, this hypothesis was based almost exclusively on studies of skin conductance which is modulated by many factors and, thus, shows rather non specific responses. On the contrary, it has been shown that only slight differences occur in heart rate and blood pressure of non hypnotized Highs and Lows during pain imagery (Paoletti et al., 2009), which puts into question the Wickramasekera's theory . A limitation of the study is the lack of evaluation of the respiratory pattern. Indeed, this is modulated by imagery of costochondral pressure pain in Highs, but not in Lows (Paoletti et al., 2009), and might have biased the results. However, the findings concerning the CoP movement during segmental pain imagery indicate that non hypnotized Highs can modulate sensori-motor integration (Carli et al., 2008; Santarcangelo et al., 2008a; Menzocchi et al., in press a, b) more efficaciously than autonomic control (Paoletti et al., 2009) .

Part IV

General Conclusions

The main outcome of the experiments described in Part 2 is that hypnotizability may account for a part of the variability of the general population in sensori-motor integration. Indeed, Highs show a pre-eminently centrally driven control of posture, while Lows undergo a more strict peripheral control (Study 1 and 3; Santarcangelo et al., 2008a, b) (Fig. 22).This has been observed also in studies on locomotion indicating that neck rotation does not modify the direction of walking in blindfolded Highs while Lows veer toward the direction opposite to their face, which indicates, in Highs, a greater ability to shift from a multisensory reference system to an egocentric one exclusively based on leg proprioceptive information (Menzocchi et al., 2009). In addition, the various sensory inputs – visual, vestibular, proprioceptive - display a hypnotizability-dependent relevance in the control of posture. Indeed, the differences between Highs and Lows elicited by alteration of the visual and leg proprioceptive inputs (Study 1;Santarcangelo et al., 2008b) are more clear-cut than those induced by modulation of the neck proprioceptive information (Santarcangelo et al., 2008a) and by vestibular impairment (Study 2). Moreover (Part 3), Highs are more prone than Lows "to translate" imagery into perception (Study 4 and 5) (Fig. 22) and to select the proprioceptive modality of imagery, when requested to imagine changes in their own body schema. The greater ability to imagine through the somatomotor modality makes Highs more able than Lows in the construction of a body somatomotor context and is in line with the peculiar role of somatic information (with respect to the visual one) in the Highs' imagery processes observed in studies on the attentional cost of imagery in the various sensory modalities (Carli et al., 2007a, b.). All together these observations- different reactions to sensory alterations, different abilities to construct new sensory contexts, different ability to select the appropriate imagery modality- raise an interest into a possible role of hypnotizability as a factor influencing the construction of the individual sensori-motor "self" (Fig. 22). The occurrence of different modes of sensory- motor integration recently suggested in animals and concerning the different role of the neck proprioceptive input in the vestibular nuclei activity modulation (Gdowski and McCrea, 2000; Roy and Cullen, 2001; Sadeghi et al., 2009) is in line with this hypothesis .

Differences in the integration of the various sensory modalities involved in postural control could be due to the activity of several structures (Fig. 23). The cerebellum receives information from all sensory modalities and influences the motor output by tuning the coupling of sensory signals and motor responses (Manzoni, 2007); it is responsible for the construction of effective internal models via comparison between central programs and sensory re-afferences (Ito, 1981) and might be involved in processes assigning a different weight to each sensory modality, eliciting differences in the motor

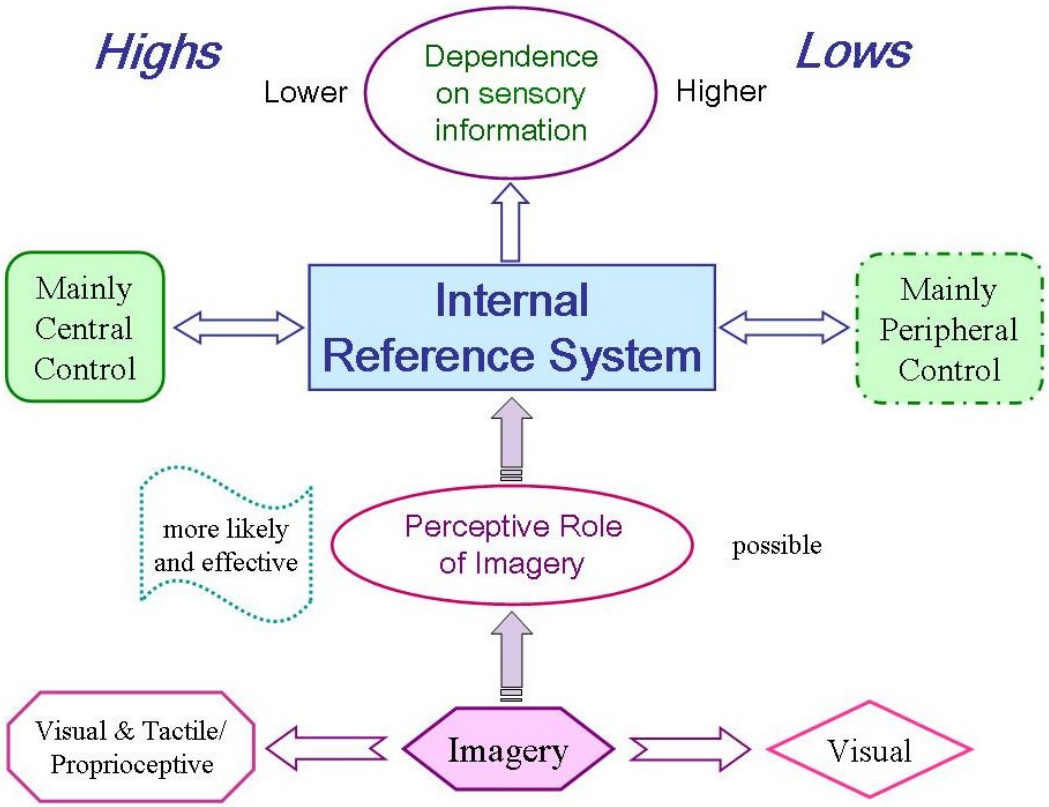

Figure 22: Schematic view of the differences between Highs and Lows

output and allowing learning. In particular, the cerebellum is responsible for the shift of the main component of vestibular reflexes from the frontal to the sagittal plane during real tonic head rotation (Shaikh et al., 2005; Manzoni, 2005; Kammermeier et al., 2009), and, maybe, during successful imagery of it. Differences could also derive from a possible hypnotizability-related distribution /activity of dopaminergic afferents (modulating mainly the activity of associative and motor areas) (Bloom et al., 1998) and involved in both hypnotizability and motor control, as a higher dopaminergic activity in the Highs' brain has been suggested (Spiegel and King, 1992; Raz, 2005; Lichtenberg et al., 2004; 2008a), although not unanimously confirmed (Lichtenberg et al., 2008b). Most of the dopaminergic projections to the cerebral cortex originate from the locus coeuruleus (LC) which receives inputs from prefrontal cortex and anterior cingulus as well as from vestibular nuclei and projects to sensori-motor and associative cortices, thalamus, cerebellum, hypothalamus, hippocampus, brainstem sensory/ motor nuclei, dorsal/ventral horn of the spinal cord (see Carli et al., 2008) LC fibers are responsible for modulation of the signal-to-noise ratio both at spinal and supra-spinal level. In particular, VS reflex adaptation is suppressed by blockade of nora-

drenergic beta receptors within the cerebellar regions involved in VS control (Andre et al., 2005). LC fibers promote alertness and attention, improve signal detectability (Aston-Jones et al., 1999; Berridge and Waterhouse, 2003) and modulate motor functions, i.e. vestibulospinal and cervicospinal reflexes (Manzoni et al., 1989; Pompeiano et al., 1991). The apparent lower dependence of the Highs' postural and locomotor behaviour on sensory information might be also sustained by more "cross talking" among cortical regions (see Pennartz, 2009), as occurs in synesthaesers (Hubbard and Ramachandran, 2005; Barnett et al., 2008) and in Highs receiving post hypnotic suggestions (Kadosh et al., 2009). In addition, hypnotizability-related hierarchies of sensory information, differences in their processing by associative areas (see Ladavas, 2008; Seemungal et al., 2008; Pennartz, 2009) and modulation by other hypnotizability-dependent cognitive functions, i.e., attention and imagery, could be hypothesized. Indeed, attention could re-direct cortical processing according to the available sensory information (see Carli et al., 2008) and imagery might exert a "perceptive" role more likely and, some-

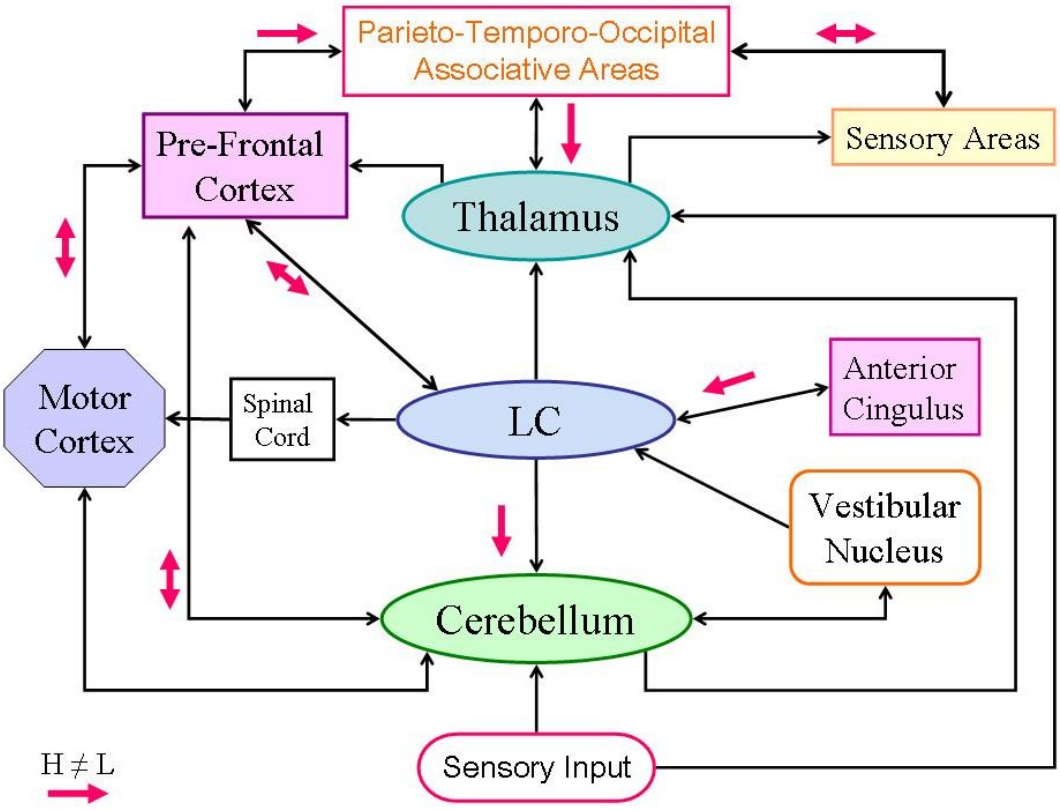

Figure 23: Hypotheses of hypnotizability-related functional connections

A novel hypothesis possibly accounting for hypnotizability-related dif-

ferences in sensori-motor integration and, maybe, for other peculiarities of Highs and Low refers to the possible role of nitric oxide (NO) in the brain. NO is produced by both the neuronal derived NO synthase (nNOS), widely distributed in neurons but present also in vessels, and the endothelial derived NO synthase (eNOS). Recent studies (Paoletti et al., 2009) have shown that the hypnotizability-related differences in the brachial artery diameter control observed during cognitive stress (Jambrik et al., 2004; 2005) and nociceptive stimulation (Jambrik et al., 2005) can be accounted for only by higher availability of both eNOS and nNOS derived NO in the Highs' vascular endothelium (Paoletti et al, 2009). Similar higher availability in the brain vessels might increase the regional blood supply through NO dependent vasodilation elicited by the increased shear stress (as occurs in peripheral vessels) present in vessels of regions involved in a task and also influence neuronal function due to NO diffusion from vessels to the extracellular compartment. In conclusion, although studies on the relation between hypnotic susceptibility and sensori-motor integration are quite recent and much work has still to be done, we suggest that hypnotic susceptibility is a highly pervasive trait modulating not only the subjective experience, through specific suggestions dissociating the subjective experience from the real environmental and physiological conditions (Hilgard 1986; Bowers 1992; Comey and Kirsch 1999), but also modulating physiological functions, i.e. sensorimotor integration and autonomic control, even in the absence of suggestions and conditioning/expectations procedures. Thus, on one hand hypnotizability might become a model for advanced integrative approaches to cognitive science. On the other hand, it may orient clinical trials for individualized neuro-rehabilitative treatments based on specific sensory stimulation and appropriate imagery training.

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Hypnotizability in the debate on Self

The individual Self is largely based on the body and on its relation with the environment, thus sensori-motor integration that is the experience of body and action influences its development and maintainance (Gallese and Sinigaglia, 2020; Metzinger, 2003, 2009). It cannot be assessed whether the cognitive trait of hypnotizability emerges in the individual personality due to experience or it is exclusively determined by genetic factors. However, its multidimensionality could behardly accounted for only by genetic determinants. Thus, it is likely that the interaction between bottom-up and top-down processes in particular individuals may induce both different levels of hypnotizability and different modes of sensori-motor integration.

List of Figures

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Part V

Appendix

Appendix A

Methods of analysis of posture

Posture is defined as the position of the body in space, and it is the result of a dynamic, adaptive process involving sensorimotor integration and attention. Posturography, the study of human posture, deals with static, quiet standing, and dynamic, gait, reaching, conditions. In this work only static posturography is considered. Keeping body's balance requires a constant control, quiet upright standing, indeed, is far from being a static state, as body sway is always present. The study of body sway can be performed by means of a stabilometric platform, which consist in a rigid surface equipped with force transducers. The subject standing on the platform activates the transducers, the signals, elaborated by a software, provide the position of the resultant, the Centre of Pressure exerted by the body.

$$CoP = \frac{\sum_i s_i CoP_i}{S} \tag{A.1}$$

where S is the total surface of contact and s_i are the surface elements. By tracking the Centre of Pressure displacement in time and space, the classical postural parameters can be obtained:
$Xmean, Ymean$ = mean value of the projection of the CoP path on the frontal and on the sagittal plane respectively as a function of time.
$Velocity$ = mean velocity of the Centre of Pressure
$Area$ = area of the ellipse containing 95% of the Centre of Pressure path
LFS = length of the Centre of Pressure path divided by the Area swept.

In this work, the stabilometric platform was a fixed squared surface, side $L = 50mm$, where the feet position was determined by removable guides, in order to let subjects stand in a fixed position.

The force transducers were disposed on a equilateral triangle to provide the force components $F1$, $F2$, $F3$ from which the CoP coordinates, X,Y,

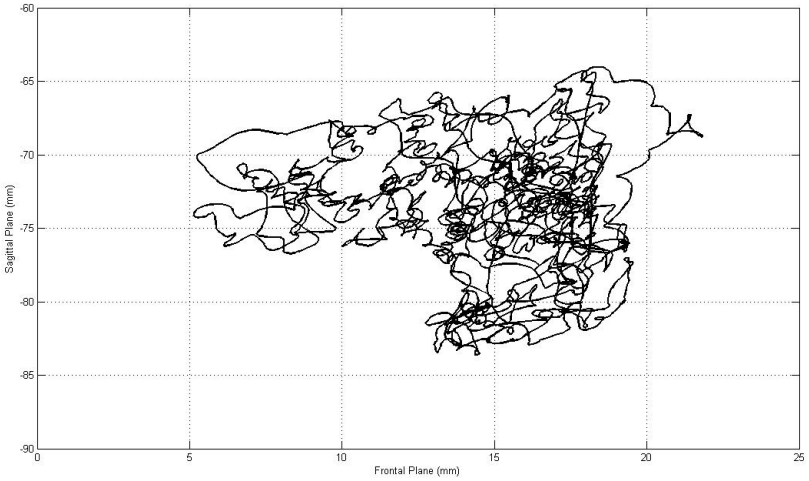

Figure A.1: Example of body sway, the resultant of the forces, exerted on the platform by the subject, is applied on the Centre of Pressure, describing a complex trajectory.

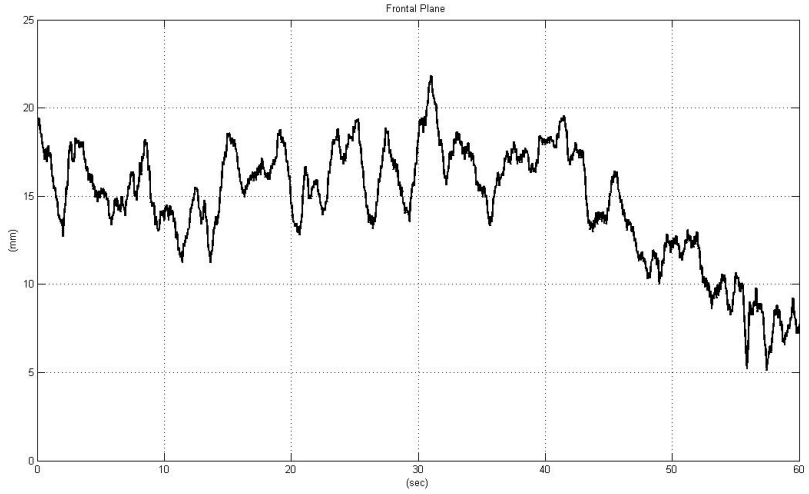

Figure A.2: Example of a stabilogram: CoP movement projections on a plane as a function of time.

can be derived with the following relationships:

$$F = F1 + F2 + F3 \tag{A.2}$$

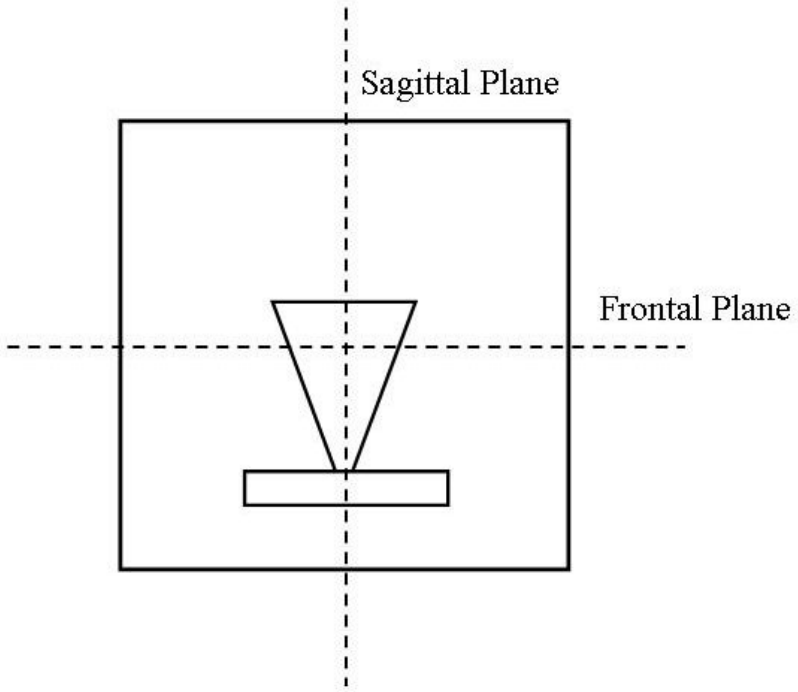

Figure A.3: Subjects stood barefoot on the stabilometric platform (NI-DAG 6.9.3, DUNE) in a standard position with heels 2 cm apart and feet at an angle of 35°

$$X = \frac{L(F2 - F3)}{2F} \tag{A.3}$$

$$Y = \frac{L(F2 + F3)}{2\sqrt{3}F} - 40 \tag{A.4}$$

Because of the remarkable complexity of postural signals, along with standard postural parameters and statistics, a new set of mathematical and statistical tools have been introduced to allow a meaningful identification of the posture control system characteristics. Stabilogram Diffusion Analysis is an example, (see Appendix B) which considers the similarity of a posturogram to Brownian motion.

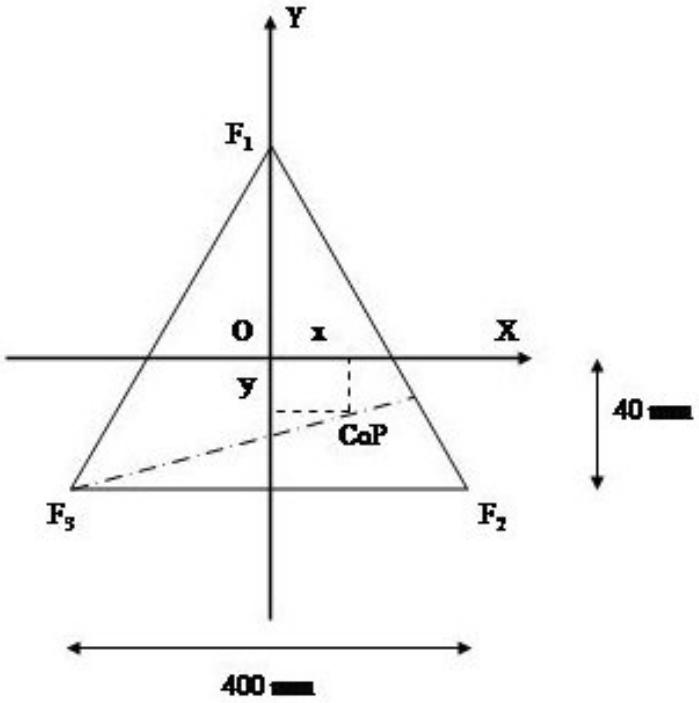

Figure A.4: Position of the force transducers with respect to the platform axis system.

Appendix B

Stabilogram Diffusion Analysis

Stabilogram diffusion analysis has been introduced by Collins and De Luca (Collins and De Luca 1993) as "a new conceptual and theoretical framework for studying the human postural control system". Based on the assumption that maintaining upright stance could be considered, at least partially, the result of a stochastic process, the analysis of CoP trajectories, stabilograms, can be performed using mathematical techniques borrowed from statistical mechanics, in particular, the diffusion equation. Comparing CoP trajectories to a Brownian motion, the diffusion equation represents the mean square CoP displacement as a function of the time interval between two subsequent CoP positions:

$$\langle \Delta x^2 \rangle = 2D\Delta t \tag{B.1}$$

where D is the diffusion coefficient.
However, in Brownian motion, the position at time t is uncorrelated to the one at time t+Δt, while CoP positions may be not. Thus, it is necessary to generalize the diffusion equation by taking into account of the "memory" of the system, introducing a scaling exponent H:

$$\langle \Delta x^2 \rangle = \Delta t^{2H} \tag{B.2}$$

where H is a real number between 0 and 1.
If $H = 1/2$, the motion is uncorrelated, like in a classical Brownian motion.
If $H < 1/2$, $x(t)$ is negatively correlated with $x(t + \Delta t)$.
If $H > 1/2$, previous positions are positively correlated with future positions.
Mean square displacements are calculated by:

$$\langle \Delta r^2 \rangle_{\Delta t} = \frac{\sum_{i=1}^{N-m} (\Delta r_i)^2}{N - m}$$

where Δr_i is the CoP displacement from (x_i, y_i) to (x_i+m, y_i+m) during a Δt time interval, m is the m^{th} step, and N is the total number of steps. The scaling exponent H is the half slope of Log-Log time interval-mean square displacement plot, $H = \frac{1}{2} SlopeLog - Log$ Fig. B.1 The stabilogram is the projection on a plane, Frontal or Sagittal with respect to the subject, of the Centre of Pressure path as a function of time In quiet upright standing two different control mechanisms have been identified: a short-term, ruled by an open loop control system, and a long term one, where a closed loop control system subsequently comes into play.

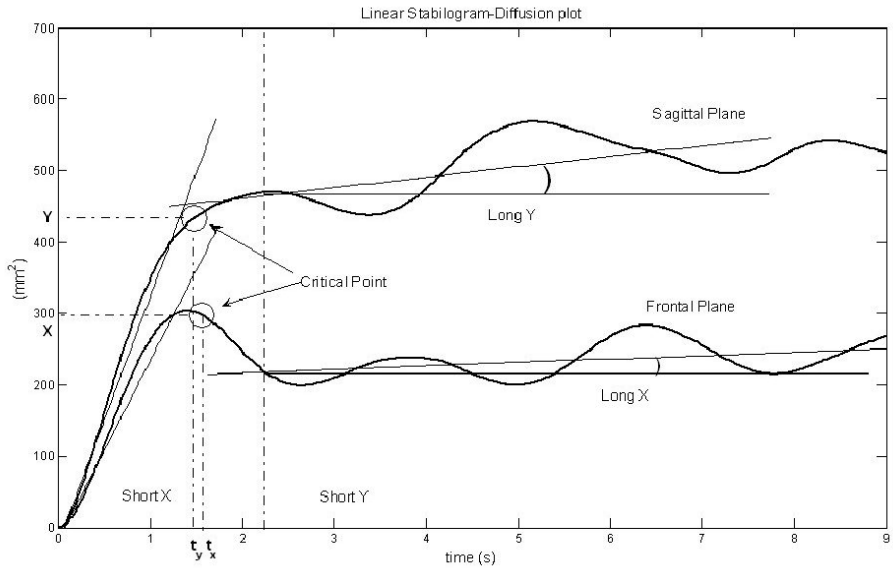

Figure B.1: Stabilogram Diffusion Analysis identifies two different mechanisms in posture control for Short and Long term. Characterizing parameters are: the Critical Point coordinates, where the open loop, short term, control shifts to closed loop, long term, and the slopes of the regression lines in short and long term.

SDA (Fig.B.1) identifies the regression lines of the mean square CoP displacements corresponding to the short- and long-term intervals, and the point (critical point) in which the CoP movement shifts from an open loop to a closed loop control in both the frontal and sagittal planes. Thus, the higher the abscissa of the critical point, the longer the time before the shift from an

open to a closed loop control occurs, or, in other words, from a central control to a peripheral one, allowing sensory reafferences modulate the reaching of equilibrium. For the same reason higher values of the ordinata indicate longer CoP trajectories covered before the shift. Larger slopes of the regression lines of the short- and long term diffusion coefficients imply greater instability of sway since, for a certain time interval, a larger slope corresponds to a larger mean square of displacement or greater sway magnitude. Considering standing subjects as dynamic systems, the variations in SDA results through experimental conditions can be interpreted as the response of a dynamic system regulated by a Proportional-Integral-Derivative ($P.I.D.$) controller whose equation is:

$$u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(t)dt + K_p T_d \frac{de(t)}{dt}. \tag{B.3}$$

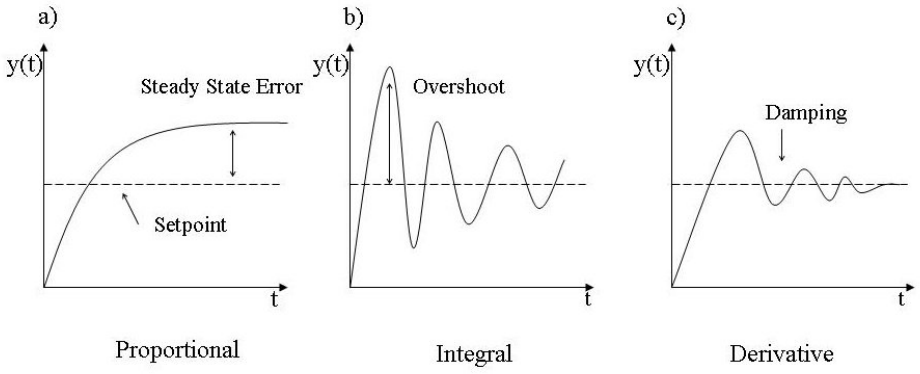

Figure B.2: Effects on a dynamic system of the components of a P.I.D. controller: a) Proportional term, b) Integral, c) Derivative.

In this equation, K_p is the proportional gain, T_i is the integral time and T_d is the derivative time. According to this model, the proportional term only gives a rough estimation of the set point, being the output proportional to the error, and the integral term accelerates the process toward the set point, but is responsible for overshoot due to the sum of past system errors. On the contrary, a derivative controller reduces the rate of change of the output, thus reducing the overshoot but requiring a longer time to reach the set point (Fig.B.2). It has also been suggested that SDA may reflect, in

the short term, an exploratory behaviour, aimed to provide the perceptual system with a constant source of information. In the long term, SDA data are indicative of a performatory behaviour that utilizes the collected information in order to maintain the upright posture (Riley et al., 1997a,b).

The abscissa and ordinata of the critical point- in the frontal (t_x, x) and sagittal (t_y, y) planes as well as the slopes of the fitting lines identifying the short and long term control periods in the frontal $(shortX, longX)$ and sagittal planes $(shortY, longY)$ were considered for analysis.

In the present work, CoP sample time was (Δt) of 1/100sec. For each Δt, the squared values of the successive CoP displacements were computed and plotted as a function of the corresponding Δt (stabilogram-diffusion plot). SDA was performed on the averaged 3 trials, to allow subject-specific pattern to emerge.

The original tables of Collins and De Luca (Collins and De Luca, Exp. Brain Res. 1993) are reported to illustrate the hypothesis that the variability observed in their sample may be accounted for by hypnotizability. Indeed, the percentage of the subjects exhibiting larger critical point coordinates in their samples is approximately the same percentage of Highs usually found in the general population and (Carvalho et al., 2008, De Pascalis et al., 2000) in the samples studied in the present experiments.

Subject	Mediolateral (x)		Anteroposterior (y)		Planar (r)	
	Δt_{xc}	$\langle \Delta x^2 \rangle_c$	Δt_{yc}	$\langle \Delta y^2 \rangle_c$	Δt_{rc}	$\langle \Delta r^2 \rangle_c$
1	0.88 ± 0.27	5.38 ± 1.01	0.42 ± 0.32	3.67 ± 2.93	0.61 ± 0.28	9.26 ± 3.57
2	1.20 ± 0.16	5.28 ± 0.40	1.67 ± 0.15	12.85 ± 1.99	1.50 ± 0.10	18.15 ± 2.25
3	0.87 ± 0.17	5.44 ± 1.49	0.33 ± 0.15	3.55 ± 2.14	0.55 ± 0.08	9.34 ± 1.22
4	0.81 ± 0.14	4.15 ± 1.02	1.28 ± 0.67	9.68 ± 5.02	1.06 ± 0.33	13.80 ± 5.40
5	0.83 ± 0.08	5.32 ± 1.02	1.57 ± 0.54	9.57 ± 4.21	1.15 ± 0.27	14.28 ± 3.14
6	1.30 ± 0.16	10.48 ± 2.15	1.36 ± 0.19	18.86 ± 3.37	1.33 ± 0.05	29.37 ± 5.04
7	1.25 ± 0.36	7.15 ± 1.62	1.21 ± 0.54	6.68 ± 2.37	1.23 ± 0.40	13.90 ± 3.45
8	1.23 ± 0.31	2.84 ± 1.24	1.35 ± 0.21	6.51 ± 2.03	1.35 ± 0.10	9.46 ± 1.53
9	1.10 ± 0.68	5.65 ± 3.24	1.00 ± 0.25	7.22 ± 0.97	0.85 ± 0.26	11.03 ± 3.76
10	1.04 ± 0.39	1.10 ± 0.26	0.56 ± 0.18	1.58 ± 0.39	0.72 ± 0.23	2.80 ± 0.64
GM ± SD	1.05 ± 0.32	5.28 ± 2.73	1.07 ± 0.55	8.02 ± 5.44	1.04 ± 0.38	13.14 ± 7.34

Group means (GM) and standard deviations (SD) for the respective parameters are given in the last row

Figure B.3: Stabilogram diffusion analysis of the first population: subject 6 critical point ordinate in Frontal ($\langle \Delta x^2 \rangle$) and Sagittal plane ($\langle \Delta y^2 \rangle$) are higher (Collins and De Luca, (1993))

Parameter		Range	Group Mean ±SD
Diffusion coefficients ($mm^2\,s^{-1}$)	D_{xs}	1.05–12.44	3.94±2.81
	D_{xl}	0.17–2.09	0.54±0.47
	D_{ys}	2.57–16.03	7.27±4.11
	D_{yl}	0.43–6.73	2.51±1.76
	D_{rs}	3.62–26.03	11.21±6.43
	D_{rl}	0.60–7.51	3.05±2.06
Scaling exponents	H_{xs}	0.63–0.81	0.74±0.05
	H_{xl}	0.12–0.32	0.23±0.05
	H_{ys}	0.70–0.83	0.77±0.04
	H_{yl}	0.18–0.50	0.38±0.10
	H_{rs}	0.70–0.82	0.76±0.04
	H_{rl}	0.18–0.45	0.34±0.08
Critical point coordinates (s)	Δt_{xc}	0.63–1.85	1.06±0.42
	Δt_{yc}	0.35–1.85	0.97±0.46
	Δt_{rc}	0.44–1.30	0.92±0.29
Critical point coordinates (mm^2)	$\langle \Delta x^2 \rangle_c$	1.88–20.70	7.75±5.74
	$\langle \Delta y^2 \rangle_c$	3.87–47.63	12.69±10.71
	$\langle \Delta r^2 \rangle_c$	5.50–64.64	19.65±15.72

Figure B.4: Stabilogram Diffusion Analysis of the second population, the Critical point ordinate (mm^2) varies with an order of magnitude in both Frontal ($\langle \Delta x^2 \rangle$) and Sagittal plane ($\langle \Delta y^2 \rangle$)(Collins and De Luca (1993)).

Appendix C

Statistical significant results

variable	**SDx**				**SDy**			
support	*firm*		*foam*		*firm*		*foam*	
Group	CE	MC	CE	MC	CE	MC	CE	MC
H	5.00	3.09	12.11	10.56	11.33	5.37	16.32	11.27
H	4.55	3.53	6.97	6.25	8.32	6.21	13.54	7.95
H	4.44	3.19	6.74	5.71	7.48	6.07	9.82	7.64
H	2.80	1.94	6.23	4.17	3.72	2.44	9.81	6.30
H	3.59	3.25	7.64	5.30	8.04	4.92	10.15	6.35
H	2.71	2.07	5.17	4.47	5.05	3.11	7.67	6.51
H	3.65	2.07	7.57	7.88	4.74	2.92	8.02	6.36
H	4.22	3.20	10.62	10.71	5.18	4.09	25.36	21.01
H	5.08	4.33	8.40	5.73	6.02	5.56	10.78	8.30
H	1.53	3.43	9.43	13.26	3.99	5.22	15.99	16.50
H	2.03	2.68	4.09	3.69	1.21	1.68	2.47	2.27
L	4.35	3.33	7.20	6.53	6.54	5.42	10.25	10.52
L	2.90	3.86	18.34	14.84	5.61	8.57	18.49	17.23
L	1.75	1.59	9.67	7.10	3.20	2.55	14.42	8.72
L	3.71	3.00	4.63	4.78	4.48	3.04	8.35	7.47
L	4.70	1.81	8.17	7.79	3.29	4.87	10.97	9.13
L	3.77	3.20	8.00	4.88	3.84	3.75	7.05	7.86
L	2.67	2.48	4.71	4.43	1.56	1.48	2.79	2.71
L	2.30	1.81	6.81	4.29	1.45	1.08	4.07	2.48
L	3.94	3.18	6.20	3.60	2.35	1.88	3.74	2.20
L	2.04	3.00	5.21	5.70	3.11	6.28	5.91	9.22
L	1.85	1.72	6.40	5.63	3.95	3.89	9.43	8.28

Table C.1: CoP Standard Deviation

Condition	F(1,20)=118.83***	*foam*>*firm*	
Eyes	F(1,20)=141.91***	CE>OE	
Cond x Trial	F(2,40)=6.50**		
Cond x Eyes	F(1,20)=53.56***		
Eyes x Group	F(1,20)=5.93*		
	Highs	OE<CE	F(1,9)=57.09***
	Lows	OE<CE	F(1,9)=15.44***
	Highs>Lows	CE	t(1,20)=2.243*
Trial x Eyes x Group	F(2,40)=3.37*		
	Highs	T1=T2=T3	
		OE<CE, T1	t(1,9)=6.336***
		T2	t(1,9)=5.232***
		T3	t(1,9)=6.941***
	Lows	T1 > T3	F(1,11)=6.706*
		T2 > T3	F(1,11)=8.268*
		OE<CE, T1	t(1,11)=5.595***
		T2	t(1,11)=8.679***
		T3	t(1,11)=7.340***
		OE, T2>T3	t(1,11)=3.737**
		T1>T3	t(1,11)=2.765*
		CE, T1>T3	t(1,11)=2.376*
	Highs > Lows	T2, CE	t(1,20)=2.8.38*
		T3, CE	t(1,20)=2.978**

Table C.2: CoP Velocity. Summary of significant results

Cond	F(1,20)=45.32***	*foam*>*firm*	
Eyes	F(1,20)=33.195***	CE > OE	
Cond x Eyes	F(1,20)=18.27***		
Group	F(1,20)=13.162**	**Highs > Lows**	
Cond x Group	F(1,20)=9.501**	**Highs**, *firm*<*foam*	F(1,9)=22.35***
		Lows, *firm*<*foam*	F(1,11)=16.08**
		foam:**Highs > Lows**	t(1,20)=12.091**
Trial x Group	F(2,40)=7.529**		
	Highs, T1=T2=T3		
	Lows, T1=T2=T3		
	Highs > Lows	T1	t(1,20)=2.316*
		T2	t(1,20)=3.809***
		T3	t(1,20)=4.155**
Eyes x Group	F(1,20)=15.301***		
	Highs	CE>OE	t(1,9)=4.848***
	Lows	CE>OE	t(1,11)= 2.406*
	Highs > Lows	OE	t(1,20)=2.689 *
		CE	t(1,20)=4.056***
Cond x Trial	F(1,20)=4.877*		
x Eyes x Group	**Highs**, OE<CE	*firm*: T3	t(1,9)=3.269**
		foam: T1	t(1,9)=2.626*
		T2	t(1,9)=3.841**
		T3	t(1,9)=4.005**
	Lows, OE<CE	*foam*: T3	t(1,11)=3.013**
	Highs > Lows	*firm* : T2, CE	t(1,20)=2.213*
		T3, CE	t(1,20)=2.791**
		foam: T1, OE	t(1,20)=2.348**
		CE	t(1,20)=2.283*
		T2, CE	t(1,20)=4.311***
		T3, OE	t(1,20)=3.342***
		CE	t(1,20)=3.858***

Table C.3: CoP Area. Summary of significant results

Condition	F(1,20)=15.117 ***	
Eyes	F(1,20)=41.588***	
Trial	F(2,40)=5.854*	
Cond x Eyes	F(1,20)=11.425**	
Trial x Eyes	F(2,40)=11.728***	
Condition x Group	F(1,20)=7.924**	
	Highs, *firm*=*foam*	
	Lows, *firm*<*foam*	F(1,11)=24.678***
	foam, **Highs**<**Lows**	t(1,20)=2.611*
Eyes x Group	F(1,20)=5.520*	
	Highs, OE<CE	F(1,9)=7.085**
	Lows, OE<CE	F(1,11)=24.678***
	Highs<**Lows**	
	CE	t(1,20)=2.291*
Cond x Eyes x Group	F(1,20)=6.553*	
	firm	
	Highs, OE<CE	F(1,9)=5.256*
	Lows, OE<CE	F(1,11)=9.805**
	foam	
	Lows, OE<CE	F(1,11)33.93***
	Lows, *firm*<*foam*	
	OE	t(1,11)=2.372*
	CE	t(1,11)=5.073***
	Highs < **Lows**	
	foam, CE	t(1,20)=3.062**
Cond x Trial x Eyes x Group	F(2,40)=4.707*	
	Lows	

Table C.4: LFS. Summary of significant results. Part 1

Cond x Eyes	F(1,11)=14.631**	
	firm, OE<CE	
	T1	t(1,11)=7.170***
	foam, T1	t(1,11)=5.376***
	T2	t(1,11)=7.516***
	T3	t(1,11)=2.880*
Trial x Eyes	F(2,22)=10.993***	
	T1>T3	t(1,11)=2.226*
Cond x Trial x Eyes	F(2,22)=5.979**	
	firm,	
	CE, T1>T2	t(1,11)=4.452***
	T1>T3	t(1,11)=6.824***
	foam,	
	OE, T2<T3	t(1,11)=4.706***
	firm<*foam*	
	OE, T3	t(1,11)=3.712**
	CE, T1	t(1,11)=3.753**
	T2	t(1,11)=6.864***
	T3	t(1,11)=4.130**

Table C.5: LFS. Summary of significant results. Part 2

effect	**abscissa**	**ordinata**	
		frontal plane	
Cond	F(1,20)=8.084**	F(1,20)=22.881***	
	firm>*foam*	*firm*<*foam*	
Eyes		F(1,20)=14.039***	
		OE<CE	
Eyes x Cond		F(1,20)=5.759*	
Cond x Group		F(1,20)=4,655*	
		Highs, *firm*<*foam*	F(1,9)=11.070**
		Lows, *firm*<*foam*	F(1,11)=20.368***
		Highs>Lows	
		foam	t(1,20)=3.395**
Eyes x Group		F(1,20)=5.713*	
		Highs, OE<CE	F(1,9)=7.991*
		Lows, OE<CE	F(1,11)=19.946***
		Highs>Lows	
		OE	t(1,20)=3.325**
		CE	t(1,20)=2.817*

Table C.6: SDA Critical Point coordinates Frontal Plane

effect	**abscissa**	**ordinata**	
		sagittal plane	
Cond	F(1,20)=6.323*	F(1,20)=27.681***	
	firm>*foam*	*firm*<*foam*	
Eyes	F(1,20)=12.354**	F(1,20)=31.496***	
	OE<CE	OE<CE	
Cond x Eyes		F(1,20)=15.306***	
Group		F(1,20)=11.881**	**Highs >Lows**
Eyes x Group		F(1,20)=9.948**	
		Highs, OE<CE	F(1,9)0=17.602**
		Lows, OE<CE	F(1,11)=18.352**
		Highs>Lows	
		OE	t(1,20)=2.712*
		CE	t(1,20)=3.395**
Cond x Group		F(1,20)07.563*	
		Highs, *firm*<*foam*	F(1,9)=14.503**
		Lows, *firm*<*foam*	F(1,11)=21.855***
		Highs>Lows	
		foam	t(1,20)=3.243**
Cond x Eyes		F(1,20)=5,380*	
x Group		**Highs > Lows**	
		firm: CE	t(1,20)=2.311*
		foam: OE	t(1,20)=2.886**
		CE	t(1,20)=3.098**

Table C.7: SDA Critical Point coordinates Sagittal Plane

plane			**frontal**				**sagittal**			
variable	**condition**	**eyes**	**Highs**		**Lows**		**Highs**		**Lows**	
critical point			mean	SE	mean	SE	mean	SE	mean	SE
abscissa	*firm*	OE	1.73	0.13	1.47	0.12	1.40	0.11	1.30	0.10
(*sec*)		CE	1.54	0.13	1.54	0.12	1.60	0.12	1.47	0.11
	foam	OE	1.41	0.11	1.36	0.10	1.31	0.09	1.09	0.08
		CE	1.36	0.07	1.23	0.06	1.44	0.10	1.16	0.09
ordinate	*firm*	OE	14.00	2.47	10.30	2.25	24.56	5.32	15.71	4.86
(mm^2)		CE	65.42	25.03	17.16	22.85	72.47	13.07	31.57	11.93
	foam	OE	63.57	7.71	29.07	7.04	91.18	12.52	42.25	11.43
		CE	172.60	26.20	57.69	23.92	334.50	53.98	108.05	49.28
slopes										
(*a.u*)	*firm*	OE	5.71	1.15	5.44	1.05	10.45	2.02	8.26	1.84
short period		CE	25.34	9.28	8.20	8.47	26.78	4.18	14.39	3.82
	foam	OE	26.33	3.07	16.74	2.80	47.14	6.88	31.81	6.28
		CE	87.16	12.81	39.88	11.70	132.15	19.34	76.07	17.65
	firm	OE	0.734	0.183	0.5516	0.167	3.60	1.02	2.44	0.93
long period		CE	0.2337	0.309	0.4584	0.282	2.49	1.13	1.39	1.03
	foam	OE	2.8018	0.499	1.1503	0.455	13.03	2.83	4.83	2.59
		CE	0.8202	0.469	0.6437	0.428	1.72	1.63	1.61	1.49

Table C.8: Stabilogram Diffusion Analysis. Slopes of the Short and Long period fitting lines. - ANOVA

variable	**area**				**velocity**				**LFS**			
support	*firm*		*foam*		*firm*		*foam*		*firm*		*foam*	
Group	CE	MC	CE	MC	CE	MC	CE	MC	CE	MC	CE	MC
H	815	180	2834	1746	13.2	5.8	35.1	48	0,89	0,54	0,42	0,25
H	554	312	1418	721	11.3	9.9	26.4	44.8	1,06	0,94	0,77	0,15
H	461	249	955	501	18	9.5	31.2	22.1	1,37	1,08	1,92	1,6
H	129	57	899	349	5.5	5.3	23.7	15.3	0,62	0,76	1,49	1,24
H	351	188	1027	470	10.2	9.9	21.6	16.4	0,86	1,16	1,23	1,19
H	157	73	577	439	8.3	7.8	17.8	16.3	0,84	1,03	1,47	1,23
H	272	95	884	790	7.4	6.7	20.4	18.6	0,86	0,73	1,06	1,29
H	229	172	3650	3424	6.8	6.5	28.6	31	0,6	0,75	0,2	0,21
H	399	335	1233	629	24.7	21.8	42.6	31	2,44	1,85	2,07	2,45
H	67	181	1958	3129	5.6	7	36.6	45.6	0,79	0,7	0,99	0,48
H	123	169	413	264	7	10.1	16.7	10.8	0,9	0,97	1,55	1,14
L	398	253	831	919	6	6.6	29.8	30.1	0,81	0,62	0,07	0,18
L	202	367	4323	4063	13	11.5	24.6	28.1	1,32	1,1	1,66	1,77
L	255	58	2166	870	8.5	7.7	57	26.4	0,95	0,83	1,3	1,71
L	208	126	526	522	11.9	11	17.2	17.3	1,41	1,13	1,5	1,52
L	230	123	1342	954	10.2	7.2	43.6	38.4	1,14	0,7	1,59	2,34
L	215	192	808	504	15.7	14.3	22.5	21.3	1,81	1,38	1,26	1,86
L	150	105	422	575	10.3	6.5	20.4	25.5	1,27	0,71	1,88	2,09
L	421	105	1129	360	12.4	7.6	21.6	14.5	1,22	0,83	1,15	1,44
L	351	256	758	411	9.8	11.4	27.6	16.4	1,08	1,11	2,01	1,62
L	93	236	447	815	7.5	17.7	18.7	28.2	0,98	1,59	1,72	1,92
L	103	97	887	690	6.7	7.3	29	35	0,86	0,78	1,84	2,59

Table C.9: CoP Stabilometric variables mean values